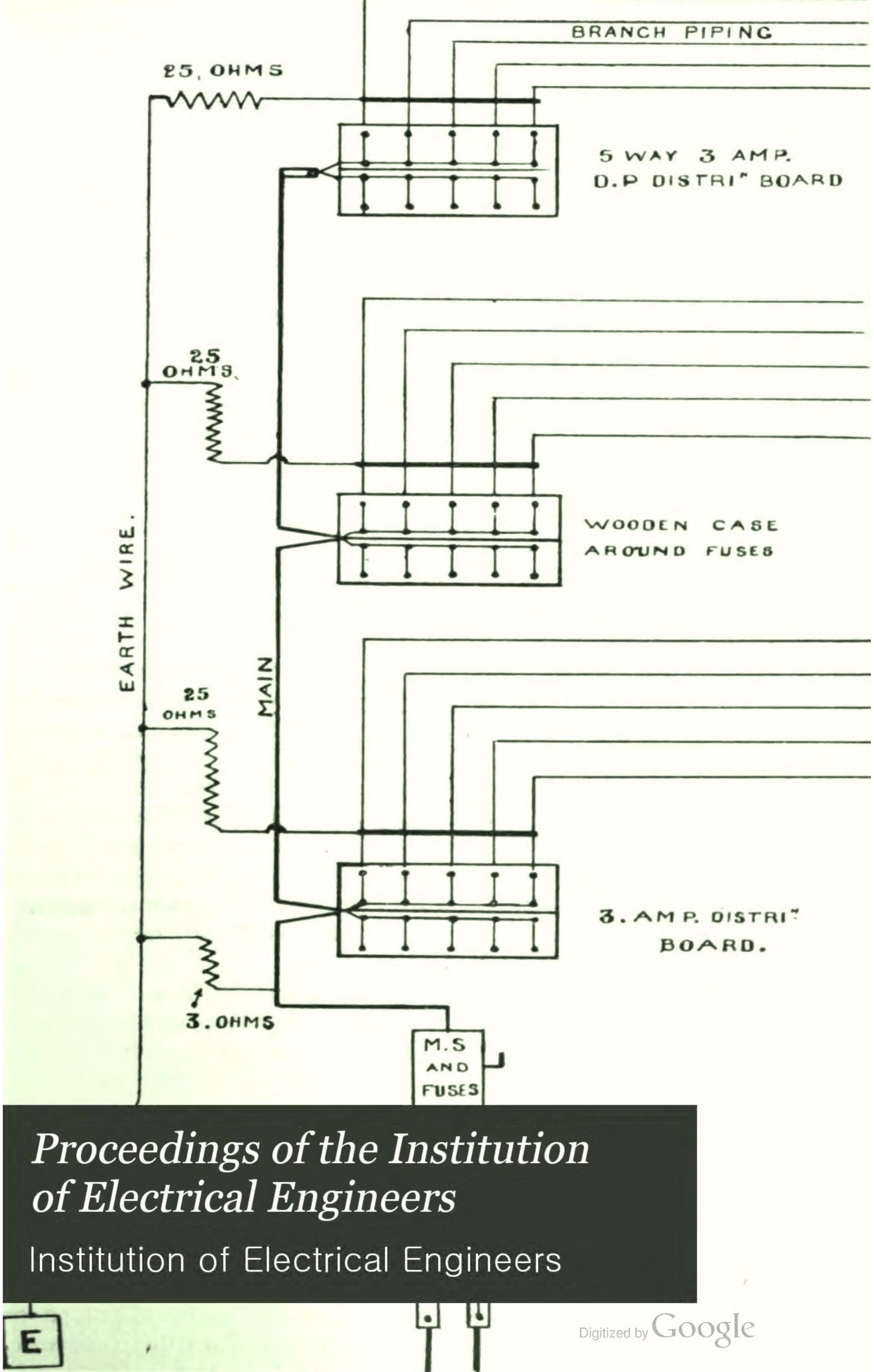

Proceedings of the Institution of Electrical Engineers

Institution of Electrical Engineers

JOURNAL

OF THE

INSTITUTION OF ELECTRICAL ENGINEERS,

INCLUDING

ORIGINAL COMMUNICATIONS ON TELEGRAPHY AND ELECTRICAL SCIENCE.

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VOL. 35.

JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 35. 1905. NO. 173.

Proceedings of the Four Hundred and Twenty-third Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 6, 1905—Mr. ALEXANDER SIEMENS, President, in the chair.

The minutes of the Ordinary General Meeting held on March 23, 1905, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council:—

TRANSFERS.

From the class of Associate Members to that of Members—
James Alexander Bell. | William Nairn.

From the class of Associates to that of Members—
Thomas Leopold Horn. | Theodor Petersen.

From the class of Associates to that of Associate Members—
Bertram G. Kelly. | Ernest Long.
William A. Kenneth. | Alexander Pope.

From the class of Students to that of Associate Members—
Arthur P. M. Fleming. | Frank Tidman.

Messrs. W. W. Cook and J. H. M. Wakefield were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

Associate Members.

Edwin J. Barker.	Alfred Charles Jolley.
Ernest James Clarke.	Richard Whitmore Jones.

Henry Raymond Wood.

Associate.

Hugh Campbell.

ELECTIONS.

Students.

Humphrey W. Bosworth.	Reginald Alexander Frank.
Maurice Balfour Chater.	Harry Norman Franklin.
Herbert Chatley.	J. G. Jones.
Tom Charles Goold Clabburn.	James Mirrey.
William Stanley Cook.	A. T. Scorey.
Harold Creagh.	Ernest J. Smallpage.
Charles Marriott Dowse.	John Henry Thomas.

Edmond Boyce Vickers.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. W. A. Del Mar, J. F. Henderson, A. P. Pyne; and to the *Benevolent Fund* from Messrs. S. E. Britton, J. Gilligan, and N. S. Russell, to whom the thanks of the meeting were duly accorded.

The following discussion then took place, and the meeting adjourned at 9.30 p.m.

DISCUSSION ON THE REPORT ON THE INTERNATIONAL ELECTRICAL CONGRESS AT ST. LOUIS IN 1904 BY W. DUDDELL, AND ON THE PAPERS ON UNITS AND STANDARDS READ BEFORE THE CONGRESS.*

(*April* 6, 1905.)

The PRESIDENT: I will now call on Mr. W. Duddell to open the discussion. The President.

Mr. W. DUDDELL: This Institution was officially represented and took a very active part in the last International Electrical Congress at St. Louis. Besides the ordinary sessions of the Congress, two joint meetings were held between this Institution and the American Institute of Electrical Engineers which possess, as such, a special interest to the members, especially as so many of our prominent engineers were unable to be present at St. Louis. It is my pleasant but somewhat difficult duty to open the discussion on some of the important points considered at the first joint meeting on Standards and Electromagnetic Units. Mr. Duddell.

I understand that it is proposed to discuss at the next meeting, in connection with a paper by Mr. Creedy, the subject of Alternate Current Motors for Traction which was dealt with by President Arnold at the second joint meeting of the two Institutions. A report to Council and the papers and discussions at these meetings have already been published in the Journal, so I do not propose to detain you by reading them.

My object in opening the discussion is to try and focus the attention of members, by a series of questions, on some of the main points in connection with Standards and Magnetic Units raised at St. Louis and so to prevent the discussion from extending over so wide a range of topics as in any way to lessen its importance.

STANDARDS.

The first point to which I wish to draw attention, although it is more a matter for experiment than discussion, is the question—(1) What is the true value of the volt and ampere? It is pretty generally admitted that the true value of the volt (10^8 C.G.S. units) is such that the E.M.F. of the Clark cell at 15° C. is very much nearer 1·433 volt than 1·434 volt the present legal value. From some recent experiments made by Mr. Trotter at the Board of Trade, it would appear that the voltage of the normal Clark cell, determined in terms of our standard ampere and ohm, is nearly $\frac{1}{10}$ of 1 per cent. less than the legalised value, so that there is a discrepancy between our legal standards of nearly $\frac{1}{10}$ of 1 per cent., though it must be noted that this does not exceed the limits of error set forth in the Order of Council.

As the volt, ampere, and ohm are connected by Ohm's law, if standards are fixed for any two the third is determined in terms of them. No one appears anxious at present to quarrel in any way with the standard mercury ohm, especially as the agreement of the standards

* See Vol. 34, pp. 171 to 228.

Mr. Duddell.

made by the National Physical Laboratory both with one another and with those constructed by the Reichsanstalt shows that this standard is reproducible to a few parts in 100,000. Accepting the present ohm, it is only necessary to legalise a standard to represent one of the other two units—(2) Is it better to adopt a standard to represent the volt or to represent the ampere?

If a standard for the volt is adopted it will probably be in the form of a cell. (3) Is the Clark (Zn) cell or the Weston (Cd) the more suitable?

If the ampere be adopted. (4) Is the Silver voltameter the most satisfactory form for this standard or should some form of current balance be used?

The various countries which have made laws on the subject of electrical units have adopted different definitions for units, although the definitions are apparently intended to specify the same unit. Thus the legal definition here in Great Britain states of each unit that it *has the value* (so much) in terms of the C.G.S. and is *represented by* a certain concrete standard, whereas in the United States Law the definition of the unit in terms of the C.G.S. system is qualified by the word "*substantially*" equal. We come, therefore, to the question—(5) Should the legally defined fundamental units be the C.G.S. units or those obtained by assigning values to the concrete standards?

Before leaving the question of standards I should like to call attention to the various kinds of standards we require, as I think that there exists a certain confusion on this subject. I am of the opinion that for each of the electrical quantities we need three standards: First, the fundamental standard (or unit), which I think we are all agreed must be the C.G.S. This, however, is not a concrete standard. Second, a concrete representation of the fundamental C.G.S. standard, or of a multiple of it. Third, the practical standard to be used in everyday work. The properties required in these standards are very different. The second standard is required to represent the C.G.S. unit or a multiple of it to as high an accuracy as is obtainable. It must be permanent, but it need not be portable nor easy to set up nor easy to use. In fact, its one object must be high permanent accuracy. These standards will, I take it, be kept and used only in the great National Standardising Institutions of the world. The tertiary, or practical, standards require almost opposite properties. They require to be cheap, portable, easy to set up and use and only need give a moderate accuracy. If they are damaged or if there is any doubt of their indication they can be compared with the National Secondary Standards.

The mercury ohm is an excellent example of the secondary standard of resistance, and its permanent accuracy is very high, but no one will suggest using it in the workshop. As tertiary standards, manganin copies of the mercury ohm are used and fulfil all the requirements. In the same way we require a secondary standard for P.D. or current, the choice need only depend on which will give the higher permanent accuracy. As tertiary standards for these quantities, a cell or a cell and resistance, will probably, in view of recent work, be found satisfactory.

Magnetic Units.

Mr. Duddell.

We require for practical purposes names for three magnetic units, viz., Magneto-motive force, Total Flux, and Reluctance. There are also three courses open in the choice of the magnitude of the units to be named. Firstly, there are already seven units with names in the practical, or volt-ampere-ohm system, to which three consistent magnetic units might be added such that the time rate of change of the flux would be in volts; the Magneto-motive force would be 4π ampere turns, and the unit of Reluctance the quotient of the unit of Magneto-motive force divided by the unit of Total Flux. Secondly, the so-called "rationalised" magnetic units might be named which involves moving the 4π from the Magneto-motive force to the Reluctance. Thirdly, the C.G.S. units can be given names. The questions which I wish to bring forward are—(6) Shall the 4π be moved? If not—(7) Shall the C.G.S. magnetic units or those consistent with the volt-ampere-ohm system be given names?

It has been suggested that all the C.G.S. units need names, and names have been put forward. (8) Do the C.G.S. electric units need names? If so—(9) How shall the names be formed?

The Chamber of Government Delegates to the Congress resolved to advise their respective Governments to appoint a permanent International Commission to deal with these questions of Units and Standards, and it is greatly to be hoped that this excellent recommendation may be carried into effect. In this event there is one final question I wish to put—(10) Can this Institution, which represents the great body of Electrical Engineers in this country, help the Commission in any way by collecting data from its members, by having experiments carried out, and by bringing the results before the Commission?

Mr. Gray.

Mr. R. K. Gray: As I had the honour to be the leader of the delegation of the Institution that went to America, perhaps a few words from me might not be amiss. I think you will find that the Report laid before you, which has been so well drawn up by Mr. Duddell, is quite worthy of your delegation. Certainly the suggestion that is made that there should be three classes of units is worthy of your very favourable recognition. I think, on the face of it, it is so useful that it cannot help being adopted. I do not want to go deeply into the question, because there are other speakers to follow me who, from their occupations and experience, are far more able to discuss the question than I am; but I would like to say that I think this country is indebted to the Institution for what it has done in connection with the matters which arose at St. Louis. Expositions and Congresses occur so frequently that some governments are hardly prepared at the proper moment to act as the interest of the country demands. In our case, we—the Institution—after appointing two Committees to study some of the matters which it was proposed to discuss at St. Louis, found that we were going over to America without the proper status; that is to say, we understood that some of the Governments would be represented in the Chamber of Delegates which the United States Government

Mr. Gray. intended to constitute, and that Great Britain had no Government delegation arranged for. The Institution stepped into the breach, and did everything in its power to get the Government to make the necessary appointments, knowing how disappointed our American friends would be if no such appointments were made. While negotiating with Government we selected some of the most representative electrical men in the country, and were glad that they placed themselves at the disposal of the Council. Through the good offices of Sir William Preece and Lord Rayleigh, who was kind enough to interest himself in the question, we succeeded in our endeavours and, whilst on our journey from Niagara Falls to Chicago, we received an intimation from the British Ambassador that delegates had been appointed by the British Government. That appointment, not only from the point of view of its usefulness in the discussions that took place, but also from the point of view of the dignity of the nation and amity with America, proved of great importance in the International gathering at St. Louis. It had been suggested to Government that Professor Perry, Dr. Glazebrook, and Colonel Crompton would be the best representative selection from among the Members of the Institution proceeding to St. Louis, and we were glad to know that this recommendation had been adopted. It is hardly necessary to state that the results of the Congress fully justified our recommendation. Before closing I should like to add that our American cousins were exceedingly good to us in every way. I would like to impress this upon Englishmen because, although we have a lingering affection for the American, at the same time we feel that he is a competitor, and a keen competitor, in business, and it is therefore very pleasant indeed to meet people who, while in that relation to us, accord us the freedom of their works and their laboratories and give us such treatment as we received at their hands. I must not occupy your time any longer, but I hope you will feel that your Council did the right thing in appointing the delegation, and that they did the right thing in appointing the men who represented us. I can assure you that in St. Louis the opinions of the men whom your Council thought fit to appoint were received with the greatest deference, and I think the opinions they expressed had considerable weight in the decisions which the Congress came to.

Lord Rayleigh. Lord RAYLEIGH: My knowledge of these questions that have been put before us by Mr. Duddell is a little antiquated. Some twenty years ago I had them almost at my fingers' ends, but since then a great deal of work has been done and many discussions have been held with which I am but imperfectly acquainted. I think Mr. Duddell has put the principal questions before the meeting in a very succinct form. One on which I should like to make a remark or two is as to the alternative of the volt or the ampere as the second principal standard. I think the discussions that have been held on this subject, as given in the Report before us, take too much for granted that there is no residual uncertainty in connection with the ohm. If the ohm were given to us from heaven, then I

Lord Rayleigh.

think there would be an immense deal to be said in favour of choosing the volt as the other standard; but if we do that we inevitably mix up two questions. The uncertainty that there may be about the ohm, and on the top of that the uncertainty that there may be about the ampere, will become inextricably mixed up together; whereas if we take the ampere as our secondary standard then we have nothing to do in that matter with any error which may attach to the ohm. The two things are perfectly distinct, and any correction that may be required for one will have no direct bearing upon the the other. That is the theoretical argument which weighed with me at the time I did my own work in favour of putting the ampere forward in the first instance rather than the electromotive force of a Clark cell. From the ordinary point of view I can well understand that the cell is exceedingly convenient; and I do not doubt for a moment that, as Mr. Duddell says, it will be used as a tertiary standard in the workshop, whatever may be done on the more theoretical side of the question. In the remarks I have made I do not mean to dispute that, at the present time, we do know the ohm more accurately than the ampere or the volt; I think that that is certainly the case. But in these matters we must look ahead, and it may be that after the researches now in progress are completed that situation may no longer exist, and that then the uncertainty about the ohm may be of the same order of magnitude as that which attaches to the ampere. With regard to the question between the Clark cell and the Weston cell, I must not speak positively, for I have no experience of my own about the Weston cell. The uncertainties which are found in the setting up of the Clark cell relate principally to the mercury end of it, and in that respect there is no difference between the Clark cell and the Weston cell. I understand, however, that at the present time these uncertainties are, if not entirely removed, at any rate in a fair way of being removed; and then we may concentrate attention upon the advantage which the Weston cell undoubtedly possesses at the other, or zinc, end in the smaller temperature coefficient to which it is subject. I suppose there is no doubt that the temperature coefficient is very much smaller, and there can be no doubt either as to the advantage of that circumstance. I believe those who have used the Weston cell will speak quite positively as to the practical advantage which it possesses in that respect. Any doubt that I should feel would only relate to the smaller time over which we have had experience of the Weston cell. In these matters one must not be in too great a hurry, and it would be well that experience should be gathered from many quarters as to the advantage of the cadmium cell if it is to be put forward as replacing the older Clark. On the question of magnetic units I do not know whether I wish to say anything. Perhaps I am too old to be an impartial witness on the 4π question, because no doubt an innovation there would upset a good deal of my mental capital, and so be positively inconvenient to me; but one must look in a matter of this sort rather to the interests of the rising generation, and I prefer to leave the matter in their hands;

Lord Rayleigh.

although I am willing to say that I object to the epithet of "irrational" which Mr. Heaviside has fixed upon the old-fashioned system. I do not think it is irrational exactly; the question is one of convenience, and in the abstract I admit the system that he prefers is the more convenient. The objection to it is simply that the other has been established. I hope that names will not be multiplied unduly. Of course, those who use them every day find no difficulty in remembering what they are; but those who turn their attention away to other branches of science, perhaps for a year or two, and then come back to electricity, are likely to be at a loss to know what is meant if too many names are introduced, and I think there is a tendency to that excess in some of the proposals that have been put forward. Another question relates to the kind of name that should be used, and here I confess I am rather horrified with the forms of some of the suggestions that have been made.

Professor Ayrton.

Professor W. E. AYRTON: A very important part of the discussion at St. Louis (at which I was unfortunately unable to be present) in connection with the subject of units was a consideration as to whether the ampere should be defined in terms of the electrochemical equivalent of silver or in terms of the ohm and the electromotive force of some standard cell. As Lord Rayleigh has most pertinently remarked, a most important point in that discussion was entirely omitted. The discussion had merely reference to what we may call our knowledge of the vagaries of the electrolytic measurement of a current and the electrolytic measurement of a potential difference, and practically no reference whatever was made as to whether the ohm was known to a very high degree of accuracy. For that reason I have had put up on the wall a diagram giving the best determinations of the ohm made in this country since 1882. You will see what the values are. I have left out the earliest one of the British Association, and some few others which were quite certainly wrong. Firstly, there is the 1882 determination by Lord Rayleigh, with the B. A. spinning coil method; this, when expressed in centimetres of mercury, one square millimetre in cross-section at 0°C., gave 106·27. Then there is the determination by Dr. Glazebrook in 1882 by a totally different method, the discharge induced by a coil turned through 180°, which gave 106·28. Next come four determinations all by the same method, viz. that of Lorenz, using the spinning disc but using different apparatus, namely in 1883, carried out by Lord Rayleigh and Mrs. Sidgwick, and giving 106·22; then by the late Professor Viriamu Jones in 1891 with his apparatus at Cardiff, 106·30; by him again in the following year, some portions of the apparatus being replaced with new, 106·32; and, lastly, the determination he made with me in London in 1897 with a Lorenz apparatus designed for the McGill University, and subsequently sent out there, leading to 106·27. The mean of the determinations is 106·28. You will see there is a good deal of difference between what may be called those six best English determinations. When I read the papers and discussion that were communicated at Chicago, I felt that there must be some other determination of the ohm that I was unacquainted

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with, some much more recent and more definite one; so Mr. Mather was so good as to spend a considerable time in going through a large number of the *Science Abstracts* to find out whether there was any such determination, but there does not seem to be any. Therefore, as a matter of fact, as regards the ohm, we are certainly not very clear as to the value of the fifth significant figure; indeed we are not absolutely so about the fourth one.

Who is the great advocate in America for defining the ampere by means of the ohm and the electromotive force of some cell? My friend Professor Carhart. I therefore looked to what has been the result of the most careful work carried out in the University of Michigan some years ago, where, as you know, Professor Carhart is Professor of Physics. In a paper by Messrs. Paterson and Guthe called "The Determination of the Electro-Chemical Equivalent of Silver," they gave, in 1898, the electromotive force of a Clark cell, and arrived at the conclusion that at 15° C. it was 1·4327 volts. In 1899, when they were using other apparatus, they arrived at the conclusion that at the same temperature it was 1·4333 volts. You might imagine, therefore, that they were approaching considerable accuracy; but if you look at Professor Carhart's paper communicated last autumn to the St. Louis Congress on the same subject, he ends by saying this: "When we have succeeded in reducing the effect of elastic fatigue in the suspension to smaller values, we shall hope to reach results accurate to at least one part in 5,000. For the present" (that is, September, 1904) "we are only prepared to say that the legalised value of the electromotive force of the Clark cell, 1·434 volts under standard conditions, is too high." So that the conclusion of all these years of very careful work in this particular direction is only that they can say that the value is too high. I do not suggest for a moment that this absence of certainty as to the absolute value of the E.M.F. of the Clark's cell arises entirely from the particular way in which Professor Carhart wants to define the ampere, in terms of the E.M.F. of a cell and the ohm; I think it is mainly due, or largely due at any rate, to the form of apparatus that he has used during all these years, modified from time to time, but still containing, I think, a fundamental mistake from a mechanical point of view. He measures the action of one coil on another by the torsion of a wire, and he is troubled, as I have already remarked, by elastic fatigue. Considering that the chemical balance has been improved for the last fifty or more years, it seems to me a mistake, when you want to carry out such a determination, not to utilise such an instrument for the measurement of force, but instead to land yourself in all sorts of troubles by preferring not to employ an instrument which is made with an enormous degree of precision at the present time. Nevertheless, this is the result of work laboriously carried out in the University of Michigan, with the idea of determining the ampere in terms of the ohm and electromotive force of a cell.

Mr. Duddell in his opening remarks spoke about the resistance of coils in this country agreeing with the resistance of coils in Germany to one or two parts in 100,000. That, however, has nothing whatever to do

Professor Ayrton.

with the absolute value of the ohm. His statement only says that you can make coils to a very high degree of similarity in resistance, but it does not show that any one of them is right. It is exactly the same thing if you refer to the standard ohm, in the English Order in Council, the standard ohm at the Board of Trade, where it says: "In the use of the above standard the limits of accuracy obtainable are as follows: for the ohm, within 100th part of 1 per cent," that is 1 in 10,000. That does not mean that we know the ohm to 1 part in 10,000; it merely states that Mr. Trotter and his staff are able to compare the resistance of some piece of wire sent to them with the resistance of another wire in the Board of Trade laboratory with that degree of accuracy—and I have no doubt that they can make that comparison to a much higher degree of accuracy.

I think people are misled into thinking that because coils can be compared with modern Wheatstone bridges to 1 part in 100,000, and can be made to agree, and can be made so that they will continue to agree within that limit of accuracy, that therefore we know the ohm, that therefore we have got a concrete representation of the ideal ohm to anything like that degree of exactitude. Therefore, I think in a sense in dealing with this question of the present realisation of the standard ampere we may put the ohm on one side. I do not say but what in a year or two we may not know the ohm in centimetres of mercury very much more accurately than we do at present; for some of you are probably aware that one of the things that Professor Jones did before he died was to get the Drapers Company to agree to give £700 for the construction of a new Lorenz apparatus to be used at the National Physical Laboratory; and I am very glad to be able to say that, although nothing had been put in writing, the Drapers Company, far from suggesting that Professor Jones's death should in any way free them from their obligation, wrote saying that they are quite willing to give this sum for a Lorenz apparatus, which they ask Dr. Glazebrook and myself to put into material form. With that instrument it is possible that we may get this fifth figure more accurately or even some idea of the sixth; but what I have told you is the state of our knowledge at the present moment. Therefore I say that for the present I should like to put on one side the question of the ohm in specifying the value of the ampere.

Now with regard to the ampere and the volt. You cannot determine the volt absolutely; you cannot, that is to say, in electromagnetic measure make an absolute determination of the volt. You can do so in electrostatic measure, but when you have done that you cannot convert your result into volts unless you know the ratio of the electromagnetic to the electrostatic unit of quantity, until you have in fact made a determination of v, and v is quite as difficult to determine accurately as the ampere or the ohm. You cannot, therefore, make a direct determination of the volt; but you can make a direct determination of the ampere with a high degree of accuracy. What is so puzzling to me is that while during the last twenty-five or thirty years there have been a great number of determinations of the

ohm, hardly any one has attempted to re-determine the ampere absolutely. Professor Ayrton

Professor Jones and I thought out how this could best be done. In all these absolute measurements you have to know the exact position of coils of wire, convolutions of wire carrying current; and therefore it is quite obvious that the old method of winding coils, such as is used in galvanometers and ammeters, which gives you a great deal of force, is wholly unsuitable for instruments for absolute measurement. You ought to employ a single layer of wire so as to be able to know exactly the position of each convolution. More than fifteen years ago Professor Jones put that view forward, and in the construction of the Lorenz apparatus, the results of which he published in 1891, he used a single layer of wire in his stationary coil, in which the metal disc rotated; and in the apparatus which we used in 1898 for the determination of the ampere we again used a single layer of wire. I refer to this preliminary Ampere Balance because a determination of the ampere was made with it, and the results published in the Reports of the British Association, and because it was a forerunner of the instrument on which I hope to say a word or two to-night, the apparatus, which has not yet been used but which is completed and ready to be tried, at the National Physical Laboratory. The stationary bobbin (Fig. A) of the preliminary Ampere Balance had two coils, and the current flowed round one of these coils in one direction and the other coil in the opposite direction, so that when the movable coil was hung inside and a current was sent through all three in series, there was a force pushing the movable coil up or down, depending on whether the current in the top fixed coil was in the same direction as the current in the movable coil, or the current in the bottom coil. The particular shape seen in Fig. A was given to the coils because it lends itself to a convenient formula for the force F between a uniform cylindrical current sheet and a coaxial helix readily expressible in elliptic integrals, viz.,

$$F = \gamma \gamma_h (M_1 - M_2),$$

where γ is the current per unit length of the current sheet, γ_h the current in the helix, and M_1, M_2, the coefficients of mutual induction of the helix and the circular ends of the current sheet.

When using this apparatus we obtained a result which, when expressed in terms of the electrochemical equivalent of silver, was so near 1·118 milligrammes deposited per second, that we felt that two points had been settled by this preliminary determination, viz., that this form of apparatus was very suitable for the absolute determination of the ampere and that it would require a very much better apparatus made on this principle in order to get the fifth significant figure, or even the fourth, with great accuracy—in other words, to get the ampere to one part in 10,000, or one part in 20,000.

The next improvement that was made by Professor Jones was to do away with the silk covering of the wire, so as to know the position of the wire with still greater exactness. In his Lorenz apparatus of 1891, and in the preliminary apparatus which we used in 1898 for the determination of the ampere, to which I have just referred, we had the

Professor Ayrton.

advantage of a single layer of wire, but it was silk covered; so that the next thing was to consider whether it was possible to do away with the silk, and to wind the wire on a helix cut on some insulating material like marble. In Fig. B is seen the coil which was first wound in this way. It was the coil used in the Lorenz apparatus, constructed by Messrs. Nalder, that was tested at the Central Technical College in 1897, by an absolute determination of the ohm being made with it, before the apparatus was sent out to Montreal. Originally this large marble ring, twenty-one inches in external diameter, was wound with bare wire, in a helix cut in the marble. The first difficulty that met us was the question of insulation between convolution and convolution. They were extremely near together; it was intended that the winding traversed by a current should be equivalent to a current sheet; the convolutions of bare copper wire almost touched, and it was extremely difficult to test the insulation. You can easily see that if you are dealing with one part in 10,000 a change of temperature of the room of $\frac{1}{40}$ deg. C. would be equivalent to a leakage of the current from convolution to convolution of one part in 10,000. Indeed, leaving even changes of temperature out of consideration, merely winding the copper wire continuously on this marble ring strains it slightly; and therefore if you tested the wire when it was straight in the air, the difference in the copper resistance due to the coiling would far more than compensate the apparent change of the resistance of the copper coil arising from leakage from convolution to convolution, corresponding with even more than one part in 10,000 of the current leaking. I tried various methods of testing for leakage such as sending a current through the coil, and measuring with a potentiometer the difference of potential from each convolution to the next, to see whether I could detect a difference in

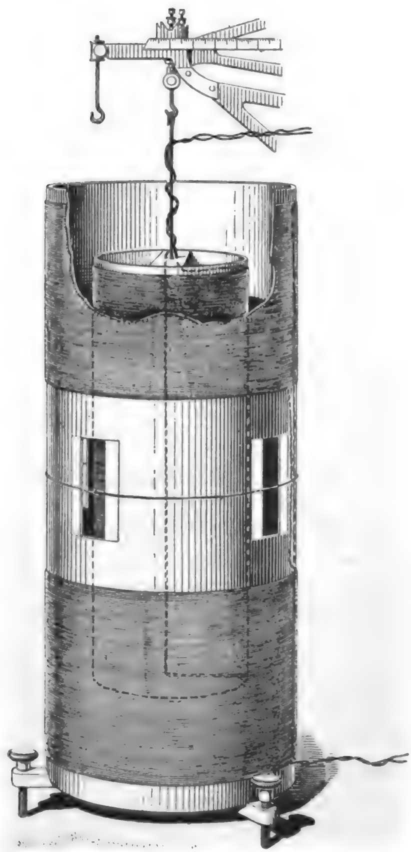

FIG. A.—Preliminary Ampere Balance.

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P.D. between certain pairs of convolutions from that which existed between other pairs; and frightfully troublesome this test was, for there were two hundred and one such convolutions.

We finally concluded that, in spite of the enormous advantage of having bare wire, it was impossible to utilise it unless the wires were put much further apart—that is to say, unless a new helix were cut on the large marble ring. Hence for the determination in 1897 we unwound the bare wire and put on silk-covered wire instead. While I was working at this investigation, an idea occurred to me which would get over the difficulty entirely, so as to use a single layer of bare wire, with convolutions close together, and yet have the certainty of very

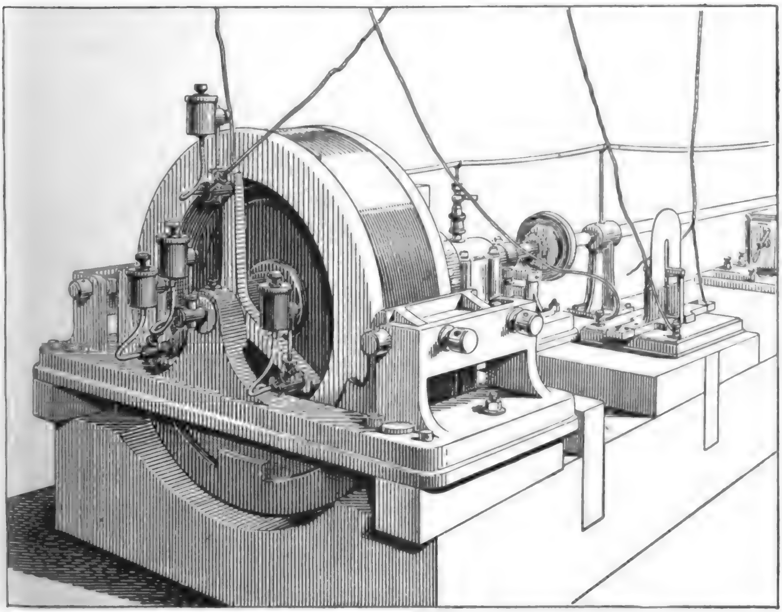

FIG. B.—Lorenz Apparatus for the McGill University.

high insulation. It is simply this; you cut a double helix on the marble and wind two separate wires in them, as shown in Fig. C. The continuous heavy line stands for one complete coil, and the light lines for another complete coil. When in use you join these two coils up in series, so that the current first runs round the one and then round the other. But you can separate electrically the one coil from the other at their ends, and you have, except at the extreme top and bottom, each convolution of the one coil between two convolutions of the other, so that the insulation resistance can be accurately tested between the two coils, and therefore between the adjacent convolutions of what becomes one coil when the two are connected at their ends. You would hardly imagine when you look at this coil (Fig. D), which was the

Professor Ayrton.

first one that was constructed by Mr. Mather to carry out this idea, that you could get such enormously high insulation. The insulation between the first, third, fifth, seventh and ninth spirals, etc., which con-

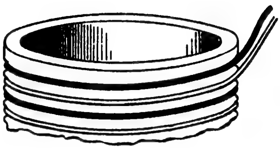

FIG. C.—Diagrammatic View of Marble Cylinder with Double Helix and Two Coils.

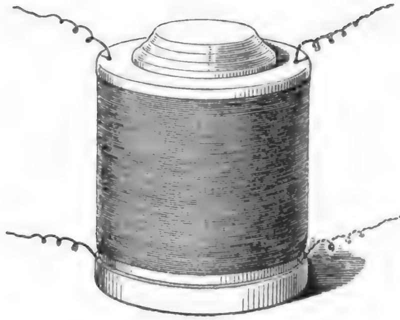

FIG. D.—Marble Cylinder with Double Helix and Two Coils.

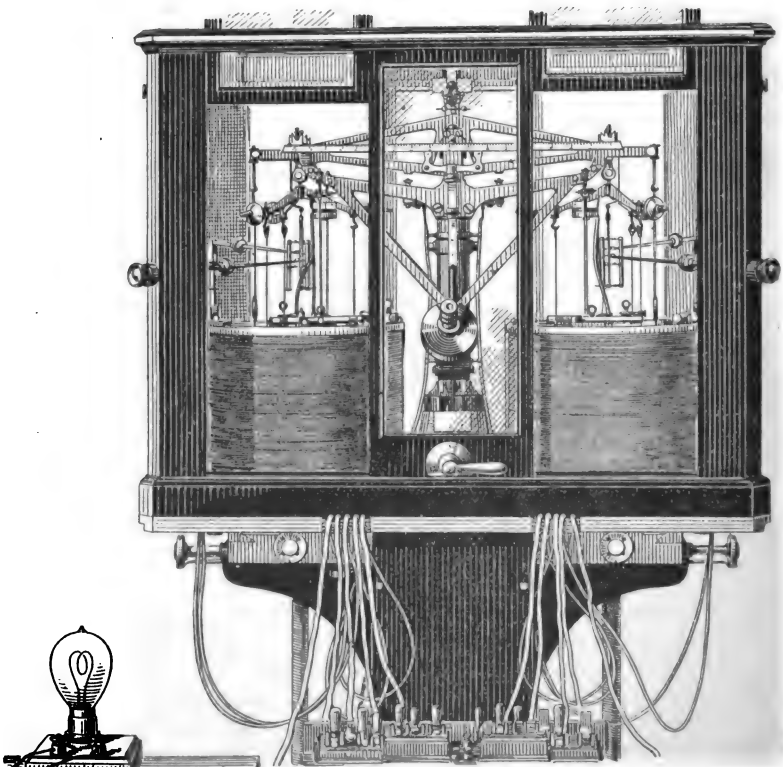

FIG. E.—Standard Ampere Balance.

stitute one coil, and between the second, fourth, sixth, eighth and tenth spirals, which constitute the other coil, is about 3,700 megohms, or was when the bobbin was first wound—that is to say, about 1,400,000 megohms per inch. If you leave the marble cylinder lying about in the laboratory and let it get dirty, of course the insulation will go down. As a matter of fact, the insulation was tested to-day, after the bobbin

Professor Ayrton.

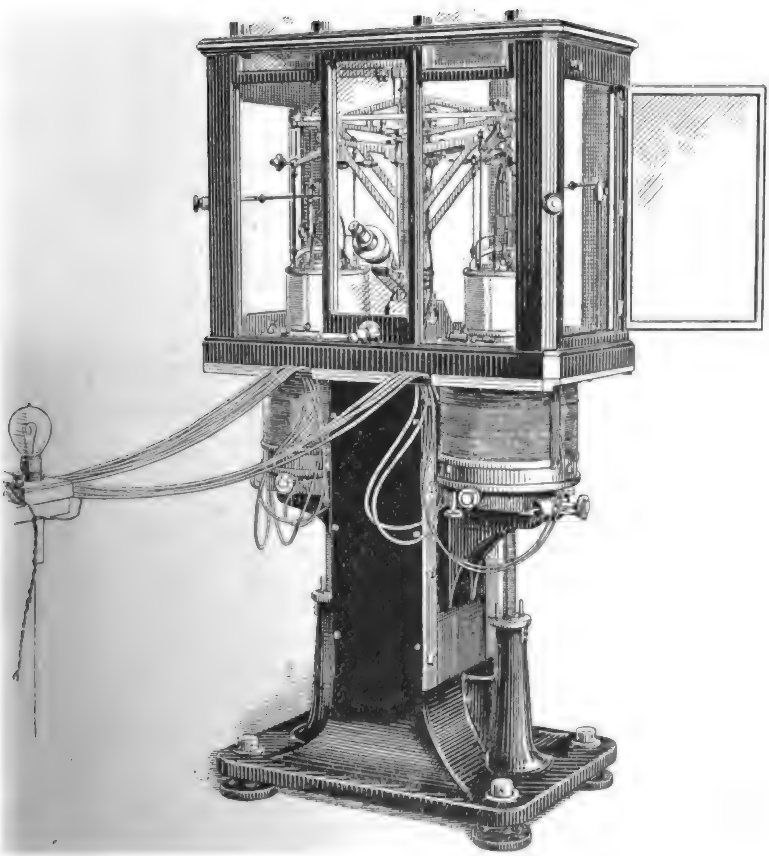

FIG. F.—Standard Ampere Balance: Fixed Coils temporarily Lowered.

had been lying about for some years; it was only 100 megohms between the one and the other even after some cleaning, but it had the very high value I have just given you when this coil was first made and when it was clean and dry.

Fig. E shows the Standard Ampere Balance in the condition in which it is at present at the National Physical Laboratory. It consists of the coils as seen in Fig. A duplicated, one set being at each end of the arm of the balance; all the coils, both fixed and movable, are wound

Professor Ayrton.

on marble cylinders, and each of the six coils, two on each fixed cylinder and one on each suspended cylinder, are really double, being wound on a double helix as indicated in Fig. C.

By means of adjustable stands the fixed coils can be lowered so as to enable the suspended coils to be examined, and in Fig. F the fixed coils are seen in this lowered position.

By means of commutators seen at the bottom of Fig. E the current, the absolute value of which it is desired to determine, can be sent in either direction through any one of the coils. When it flows as indicated in Fig. G there will be an upward force on the left-hand suspended coil and a downward force on the right-hand one, so that a weight must be added to the left-hand side of the beam to produce balance and bring the beam into a horizontal position.

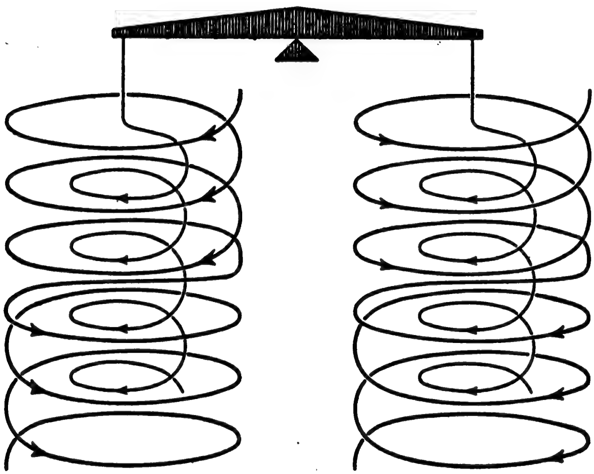

FIG. G.—Diagrammatic Sketch of the Direction of the Current Flow on the Six Coils.

Thanks to the great care which has been exercised by Dr. Glazebrook and Mr. Smith, of the National Physical Laboratory, in attending to every detail, in fact in carrying out the working drawings seen on the wall, and which were made at the Central Technical College by Mr. J. P. Gregory, now the engineer of the Central Station Department of the British Thomson-Houston Company, when he was a student at the college, we hope by this apparatus to be able to get the ampere to certainly one part in 10,000, and perhaps to one part in 20,000; so that in the course of a few weeks, or months, we trust that we shall know the absolute value of the ampere more accurately than the absolute value of any other of the electrical units which have been determined up to the present time.

Mr. Trotter.

Mr. A. P. TROTTER: Before taking part in this discussion, I wish to make it clear that my remarks are not to be understood as representing the official views of the Board of Trade.

Mr. Trotter

In the section of Dr. Wolff's paper on the Legalisation of the Electrical Units by the Various Governments, he observes that "In England . . . a distinction is made between a *unit* of electro-motive force and the *standard* of electro-motive force, the latter being defined as the $\frac{1}{150}$ part of the pressure producing a certain deflection of a Kelvin electrostatic voltmeter of the multicellular type . . ."

The distinction between a unit and a standard was discussed by the Electrical Standards Committee of 1890. That Committee was appointed "to consider and report . . . with a view of causing new denominations of Standards for the measurement of electricity for the use of trade to be made and duly verified." The distinction is to be found in the Weights and Measures Act of 1824, which, while it declared that a certain metallic bar should be considered the standard yard of the British Empire, provided for its recovery and reproduction in case of the total destruction or loss of it and all its authentic copies and facsimiles, by a declaration that its length is 36 inches, such that 39·13929 of them are equal to the length of a pendulum vibrating seconds *in vacuo* and at the sea-level, in the Latitude of London. When that standard was destroyed by the burning of the Houses of Parliament, the new standard was constructed, not by any measurement of the length of the pendulum, but by a careful comparison of all the best scales that could be got together. The Act of 1855 which constituted the legal yard, named others as its successors in the event of destruction or loss, and omitted reference to the pendulum.* Similarly the *unit* of length of the metric system is the 10,000,000th part of a certain quadrant from the Pole to the Equator, but the *standard* is the platinum bar kept at Paris. Any given unit may be defined in various different ways; such definitions are descriptions. A unit is something which we define, a standard is something which we construct and use. A standard is the material embodiment of a unit for practical purposes, and in this country the construction of material standards is necessitated by the Weights and Measures Act. In other countries the units are defined by law, but their embodiment in the form of measuring apparatus is left to authorised officials.

The Order in Council of 1894 keeps a clear distinction between a unit and a standard. It says that "new denominations of standards are required for use in trade based on the following units of electrical measurement." Then follow three paragraphs of definitions. The primary definition of the ohm is 10^9 C.G.S. The secondary definition—"and is represented by the resistance" of a certain column of mercury. The primary definition of the ampere is $\frac{1}{10}$ C.G.S. The secondary definition—"and which is represented by the unvarying electric current which" deposits a certain amount of silver per second. The primary definition of the volt is 10^8 C.G.S. The secondary definition—"being the electrical pressure that if

* Sir John Herschel, *Familiar Lectures on Scientific Subjects*, p. 429.

Mr. Trotter. steadily applied to a conductor whose resistance is one ohm, will produce a current of one ampere." The third definition—"and which is represented by" the value of the Clark cell. In these three paragraphs the word "standard" is not to be found.

The Order in Council says that new denominations of standards have been made and verified, and goes on to "approve the several denominations of standards set forth in the Schedule hereto as new denominations of standards for electrical measurement." The Schedule "sets forth" the ohm coil, and does not mention the mercury column, it sets forth the ampere balance, and does not allude to silver deposition, and sets forth the voltmeter without mentioning the Clark cell.

Unlike any other country, our Order in Council declares the limits of accuracy attainable, and this should be remembered in connection with the words "and is represented" which occur in each definition. The United States Law uses the expressions "substantially equal to" and "practically equivalent to." Germany uses the expression "practically equivalent to," and France and Belgium "sufficiently well for practical purposes," and Austria "for commercial purposes." *

In 1894 it was necessary to use definitions of the units, but now that so much work has been done on absolute electrical measurements, it appears to me that if we were starting afresh the C.G.S. definition would suffice for the units, and the selection of standards may be left to the officials of each country. Those officials will naturally be in touch with the scientific authorities, and will keep themselves informed about the values of their standards in absolute measure when important absolute re-determinations of the units are made. Mr. Duddell spoke at St. Louis of units as primary standards, and of what I call standards, as "secondary standards." I quite agree with him when he says "it would be unwise to tie ourselves too tightly to these." When it is found that the standards diverge appreciably from the units, two courses are open—one is to "scrap" the standards and the other is to apply a correction. Clerk Maxwell was of opinion that the original B.A ohm would not be altered, but that a correction would be applied, when more accurate researches had been made.†

Among the many important pieces of work which have been undertaken by the National Physical Laboratory, are the absolute of the ampere and of the ohm. When the results are declared, the Board of Trade may or may not take official action in declaring a correction or corrections. The result will be so well known to the scientific world that anybody could apply them for himself. At present, there is no reason to suppose that the standards of this country differ from the units by more than the limits of accuracy

* Gleich zu achtendem.
Elle est suffisamment représentée pour les besoins de la pratique par
Im öffentlichen Verkehre kann . . . gleich geachtet werden.

† Clerk Maxwell, *Electricity and Magnetism*, vol. i., p. 389.

which have been laid down. It speaks volumes for the careful work of the Committee of 1890 that after 15 years so little alteration is needed. The Committee never suggested that the mercury column should be used as a standard. The mercury column is as good a definition for international purposes as could be devised. The 106·3 centimetres may be revised from time to time as more refined research work is carried out, and the revised figure will indicate the correction to be applied to the standard by those who are engaged in physical work involving absolute measurement. It has been suggested that the method of silver deposition described in the specification attached to the Order in Council is capable of improvement—for example, that stratification of the solution should be prevented by stirring. But the method of silver deposition is not introduced here for the purpose of defining the ampere by means of the electro-chemical equivalent of silver, it is introduced for the purpose of recording the research of Lord Rayleigh, who used that particular method. This method formed the link between Lord Rayleigh's work and the Ampere Standard Balance of the Board of Trade. When a new determination is made, other links might be devised for scientific purposes, but the precision of the silver deposition is ample for all purposes of trade. Mr. Trotter.

The only part of the work of the Committee of 1890 which needs revision is the definition by the Clark cell, and the specification of that cell. "The Board of Trade Volt Standard" has nothing to do with the Clark cell, it was not verified with reference to that cell, and it is in good working order. Without going outside the Board of Trade Electrical Standards Laboratory, a discrepancy has been discovered between the declared value of the Clark cell and its observed value. I have taken steps to let it be known, semi-officially, that this value appears to be 1·4329 instead of 1·434 at 15° C., or 1·434 at 14° C.

I am not convinced that this discrepancy of 0·788 in 1,000 is of appreciable importance "for use in trade." It is on the limits of practical importance in connection with lamp testing, for it is equivalent to nearly 0·4 of 1 per cent. of candle-power.

The specification of the Clark cell appended to the Order in Council is now out of date. I cannot recommend that form of cell for work of the highest accuracy. I think that large cells, as suggested by Prof. Schuster, are better, and it is probable that a cadmium cell is better still. Knowing the liability of Clark cells to dry up, I should prefer a saturated cell with a higher temperature coefficient to a semi-saturated cell with an almost negligible temperature correction.

Experience of the last fifteen years has shown that neither the Clark cell, nor any improvement of it, is necessary in a Standards Laboratory as a standard, while, on the other hand, such cells are very valuable pieces of apparatus both for scientific and for trade purposes. I quite agree with Mr. Duddell that what he called a third set of standards seems to have been confounded with the second. Such is the cell, an apparatus which is carried about for practical purposes, and which the practical man will take as his testing standard. It

Mr. Trotter. can easily be carried about, and can be used with the potentiometer.

The question of amending the legislation of this and of other countries has been discussed. I am not prepared to recommend to the Board of Trade that any amendment of the Order in Council is necessary.

But, if an amendment were to be made, I should recommend that the definition of the volt should not contain reference to the Clark or to any other standard cell, but that we should fall into line with Germany, Austria, Belgium, and Switzerland.

I attach but little importance to our Volt Standard as a legal standard. It is a useful laboratory instrument. If I want a Volt, I pass the Ampere through a copy of the Ohm, which will easily carry it. This is often done in the Board of Trade Laboratory, and is in accordance with the definition which would remain, if reference to the Clark cell were omitted.

I should also like to say that the 1·4329 figure which I have given for the Clark cell in terms of the ampere and the ohm is rather an interesting confirmation that we are in close agreement with the Reichsanstalt as far as the ampere is concerned, because their figure for the Clark cell is 1·4328, and ours is 1·4329, which, of course, is within the limits of observational error. Therefore I do not think our standard is very widely different as far as the ampere is concerned. It was suggested some time ago that although it is admitted that the Board of Trade Electrical Standards Laboratory is well equipped for measuring continuous current, suitability of the equipment for measuring alternating current was rather doubtful. To satisfy myself about that, I passed the continuous-current ampere, as shown upon the Ampere Balance, through the large coil of 100 ohms, which will easily carry the ampere, and observed the deflection upon the electrostatic Volt Standard. That Volt Standard is mentioned in the Order of Council, and it is declared in the Order that when the deflection passes from mark A to mark B that is the measure of 100 volts. This test had not been tried since I have had charge of the Laboratory. It was right to about 1 part in 50,000; I did not trouble to go further than that; it satisfied me for the purposes of the experiment. Then we put the alternating current through the same 100 ohms, and observed on the electrostatic instrument the pressure it took, and it agreed within about the same amount—1 part in 50,000. The question was, Was there any error in the apparatus that might be obscure? If there had been self-induction in the coils, the apparent volts would have been higher with the alternating current. The only thing which could have cancelled that out would have been capacity, which obviously was not present. But to satisfy ourselves by an external check, I looked about for a C^2R check, and I used a large Cardew voltmeter, which Major Cardew left unfinished, and which had never been equipped. It has a tube about 10 feet long, and Mr. Crawley was good enough to spend two or three days in rigging it up and fitting an optical arrangement to it, which gave a very large magnification. We used it merely as an indicator; it carried an ampere, and could show a difference of about 1 part

in 50,000. We found that the agreement within those limits was perfect. Mr. Trotter.

Mr. F. E. Smith: I would like to make a few remarks on electric standards as determined absolutely, on concrete standards, and on practical electric standards. In looking through the report of the St. Louis Congress, the first point with which I am struck is the unanimous approval of the mercury standard of resistance; there was no discussion whatever on the concrete mercury ohm. The second point which strikes me is the absence of experimental data by means of which one might obtain some idea of the accuracy with which an absolute unit can be realised; so I think it may be worth while to give some idea of the accuracy with which a concrete standard can be obtained and maintained constant, and the accuracy with which an absolute unit can be realised. To take the concrete or secondary standards in order. In the first place the mercury standard, which, as I have said before, received no criticism. To what degree of accuracy is the mercury ohm reproducible? I have previously shown elsewhere that the definition of the Chicago Congress is practically unrealisable; one cannot realise that particular mercury ohm; there is always a surface film of moisture on the wall of a glass tube; also, the axis of a glass tube is undulatory in nature, and these are important things to remember when we speak of reproducibility and constancy. The eleven mercury standards constructed at the National Physical Laboratory are such that there is a difference between the values of any one tube and the mean value of about 2 parts in 100,000; it is a little less than that, and the probable error of the mean is about 8 parts in 1,000,000. This mean value has been compared with Reichsanstalt mercury standards, which were constructed on entirely different principles. We find by that comparison that there is a difference between the standards of the two institutions of about 2 parts in 100,000; so that I think one is justified in saying that the mercury standard is a reproducible concrete unit to about 2 or 3 parts in 100,000. But then there crops up another question—Is the mercury ohm a constant one? After we have constructed these tubes, will the resistance of the mercury columns contained in them remain constant? Does the zero of a thermometer remain constant? I am not referring to an ordinary thermometer, but to a thermometer made of the same kind of glass as the mercury ohms are made of—Jena glass, or *verre dur*. We find that the zero of a thermometer is not constant; we find that its zero is subject to slight fluctuations; and from this analogy we conclude that it is possible for the mercury standard to change by about 2 parts in 100,000 after construction. I should like to say that the mercury standards of the National Physical Laboratory are not set up permanently; it is not desirable that they should be. They are subject to a certain cycle of operations before erection, which cycle of operations causes this secular change to be minimised. Moreover, it is not desirable that mercury standards should be set up permanently, because platinum leads must be inserted in the mercury, and no one knows exactly to what extent the platinum will go into solution, and what

Mr. Smith.

Mr. Smith. effect that platinum in solution would have on the resistance. In consequence, the best mercury standards of the National Physical Laboratory are not set up permanently. I might add to these remarks that if any redefinition of the secondary unit is anticipated, that instead of making normal mercury standards it is preferable to construct standards of $\frac{1}{10}$ ohm or $\frac{1}{100}$ ohm. The reasons for this suggestion I cannot very well go into now, but I estimate, on the whole, that the present mercury standard is reproducible, and will remain constant over a considerable number of years, to about 4 parts in 100,000 only. I think it would be unwise to place the figure any higher than that. I am not quite so sure as Mr. Duddell that we may not in years to come find mercury standards in the test-room; they would not be expensive, and they would afford a very convenient check indeed for manufacturers for their standard coils. As regards these latter, which are the practical standards, they are subject to very considerable variation, especially coils of high resistance; and it is for this reason that I am not sure but what we shall find the mercury ohm in the testing-room in the future. To turn now to the subject of the standard cell, I am in the main in agreement with the remarks made by Dr. Wolff and Prof. Carhart at St. Louis. I am speaking of their comments on the cadmium cell. In this country we have two cells of cadmium elements. We speak of a cadmium cell and of a Weston cell. What I refer to as the cadmium cell is referred to in the St. Louis Report as the Weston cell. The difference is this, that whereas the Weston cell is saturated below one temperature only, the cadmium cell contains cadmium sulphate saturated at all ordinary temperatures; that is to say, crystals of cadmium sulphate are always present. It is this cadmium cell which is suggested for the concrete standard at St. Louis, and which has a very small temperature coefficient; the drying up of the cell is of no consequence, as long as some liquid remains, and as long as it acts as a standard of electro-motive force. At the National Physical Laboratory there have been constructed upwards of 200 cells of various types, chiefly with the cadmium element. As long as three years ago we found that the mercurous sulphate was the element at fault. The suggestion was originally made, I believe, by Lord Rayleigh that mercurous sulphate was a very faulty element in the Clark cell. The same is true of the cadmium cell, and it is important to remember that all the disadvantages of the Clark cell, except one, are disadvantages of the cadmium cell. The mercurous sulphate may be so faulty, if the Board of Trade's specification is followed out, as to alter the electromotive force of either the cadmium or the Clark cell by $\frac{1}{400}$ of a volt—a very serious matter indeed. This, thanks to the work which has been carried out in America, and also owing to certain work carried out at the National Physical Laboratory, can now be remedied. There is no doubt whatsoever that mercurous sulphate may be obtained in a pure condition, and that it will not produce any great disturbing effect in either the cadmium or the Clark cell. I should like to say, in speaking on the question of the reproducibility of the cell, that the final act of the National Physical Laboratory will be to obtain cells which have

been constructed by many different persons using the same specification but employing materials obtained from different sources, and in this way we hope to get some idea of the reproducibility of the cadmium cell, and perhaps also of a new Clark cell. At present cadmium cells are in use at the National Physical Laboratory, and their voltage does not vary more than $\frac{1}{100000}$ or $\frac{2}{100000}$ of a volt. That is rather a high difference figure for some of the cells. Similarly, in America, Professor Carhart is making cadmium cells, of which the difference in voltage does not exceed more than $\frac{1}{100000}$ or $\frac{2}{100000}$ of a volt. But this figure, I think, does not convey a good idea of the accuracy with which the cells can be reproduced. We must have many different persons concerned in the operations. I would rather estimate the figure at which a cell can be reproduced at 4 or 5 parts in 100,000. I am very optimistic respecting the cadmium cell, and I do believe it can be produced so that immediately after construction a definite E.M.F. is ensured. But then, again, we have the other factor—will the cell remain constant or not? To this I can give no satisfactory answer. Standard cells change so slowly; they must be kept under observation for many years; and no cadmium cells have been kept under very careful observation for a long period. From theoretical considerations I may say that if a number of cadmium cells be constructed and one is faulty, so that its electromotive force is too high, its electromotive force should eventually fall to the normal level; but we have two batches of cells in the National Physical Laboratory, one lot being about $\frac{3}{10000}$ of a volt higher than the other, and they have not fallen $\frac{1}{100000}$ of a volt during the last twelve months, and that is what theory does not altogether explain. I think Professor Carhart would agree with us if we placed the figure of reproduction and constancy of the cadmium cell as somewhere about $\frac{1}{10000}$ of a volt. That is a very satisfactory figure indeed when the past history of standard cells is reviewed. I think I should in justice add some remarks with regard to the Clark cell. I have in the past, in conjunction with many others, helped to heap abuse on the Clark cell, but the Clark cell is a very good secondary standard if it be made to a new specification and be kept at a constant temperature. All the disadvantages of the Clark cell, which have been pointed out by Dr. Wolff at St. Louis, then entirely disappear, and we have the Clark cell quite as good as the cadmium cell; but for practical purposes certainly any one who has worked with both cadmium and Clark cells would prefer the cadmium standard. The cadmium cell is the cell of the future for practical purposes; its temperature coefficient is only about $\frac{3}{1000000}$ of a volt per degree, and in consequence no correction is necessary for temperature variations. With reference to the silver voltameter, I would not suggest for a moment that it be employed in the workshop. The silver voltameter is, perhaps, to be a concrete standard for the great standardising laboratories that are being set up all over the world, but it is not for general use. Is the silver voltameter preferable to the standard cell or not? I think the whole thing turns on the reproduction and the constancy. What is the constancy of the silver voltameter? That, again, is a very Mr. Smith.

Mr. Smith. difficult question. Professor Guthe says that he can repeat his determinations to 1 part in 10,000. That, I may say, confirms certain results of experiments in which I also have been interested. Perhaps when Prof. Guthe has finished his experiments in America, and when certain researches at the National Physical Laboratory have been completed, it will be possible to design a particular type of silver voltameter, which, conditionally that a constant difference of potential be maintained between its terminals, will be such that a higher degree of accuracy results than even 1 part in 10,000. Hence it is possible that the silver voltameter will be preferable to the standard cell as a secondary concrete unit. I do not think one could definitely say at the present time which is to be preferred. I would point out that when using the silver voltameter the observations are often continued for two or three hours. That is, however, quite immaterial, since these secondary standards are only suggested for the great standardising laboratories, and a current may be maintained constant in a circuit—even when a silver voltameter is included—to 1 part in 100,000, for two or three hours or more; so that we may say that with the silver voltameter an accuracy of 1 part in 10,000 is possible. We may summarise, then, the concrete units dealt with—the mercury ohm, the standard cell, and the silver voltameter. We have degrees of accuracy in their production, and in their constancy, of the order of about 4 parts in 100,000 for the mercury ohm; 1 in 10,000 for the standard cell; and 1 in 10,000 for the silver voltameter. I should not, perhaps, give such a figure as 1 in 10,000 for the cell except that I am very optimistic in connection with it. If we turn to the absolute system of units, one would not expect that such a degree of accuracy could be obtained as 1 part in 10,000, but I think in the apparatus designed by the late Professor Viriamu Jones, Professor Ayrton, and Mr. Mather, a degree of accuracy approaching 4 or 5 parts in 100,000 has certainly been obtained; and moreover, in a new Lorenz apparatus, I believe the same degree of accuracy may be secured. In consequence, the absolute units may be realised with the same degree of accuracy as the secondary units can be produced and be expected to remain constant.

Discussion at Meeting of April 13, 1905.

Dr. Glazebrook. Dr. R. T. Glazebrook, F.R.S.: I am glad to have an opportunity of saying a few words on this subject, which formed the subject of our very careful and serious consideration at St. Louis; in the first place, to be able to put on record publicly my appreciation of the efforts of our American friends to make our visit to St. Louis a great success from every point of view; and, in the second place, and no less, having due regard, sir, to your remarks as to the value of our time, to call attention briefly to one or two points in the discussions there, and to one or two matters which have been alluded to already. The first point that I should like to consider is the very important one that was raised last week by Lord Rayleigh, and was emphasised again, I think by Professor Ayrton, as to the fact that if we accept as our second fundamental standard the volt rather than the ampere, then in experimental work

Dr. Glazebrook.

for the measurement of current, the measurement of a resistance would be involved as well as that of an electro-motive force, and that, therefore, our measurements would be liable to the errors that occurred from the standard of resistance not being accurately known, as well as to errors which came from the volt itself. That point certainly was not touched upon at St. Louis, and I think the reason for it was a good one. Our work at St. Louis was to consider the realisation of a practical connected series of standards. We were not, I think, dealing so much with the absolute units, neither were we dealing entirely with the question as to whether the concrete standards that were employed in various countries represented to the highest degree of accuracy attainable the C.G.S. units of current, resistance, or electro-motive force; but we were endeavouring to establish a concrete system of standards acceptable throughout the world, and reproducible with reasonable accuracy in any properly equipped laboratory. It was felt in the discussions that the ohm, as defined by the resistance of a certain column of mercury, was a satisfactory concrete standard that could be reproduced, and that might be used in the determination of current in conjunction with measurement of electro-motive force; and, therefore, it was not necessary to discuss again the question of the ohm, neither was it necessary to discuss the question whether 106·3 centimetres of mercury represented as closely as could be 10^9 C.G.S. units, because we had a common basis for discussion in the fact that that figure had been accepted throughout the world, and that it had been shown by experiment in two or three different countries that resistances based on that figure could be reproduced and were quite satisfactory. So I think we started from the hypothesis that the ohm, meaning thereby not 10^9 C.G.S. units, but an actual concrete practical standard, was a determined quantity, and we had only to deal with the volt and the ampere. Then I should like to go on to Mr. Trotter's remarks, and to express my very cordial agreement with very much, practically with all, that fell from him on the previous evening. I should like, however, to carry what he said somewhat further in one or two respects. I was glad to find that he maintained the view so clearly, a view which I endeavoured to impress on the Congress at St. Louis, that the English legal standards of resistance, current and electro-motive force, were defined by certain schedules to an Order in Council, and had now nothing to do with the resistance of mercury or with the electro-chemical equivalent of silver, or with the electro-motive force of Clark cells—had nothing to do with them now as they stand. That, I think, is made quite clear by the form of the Order in Council, and it is a very important point. The standards are concrete instruments, and the Board of Trade Committee to which their initiation is due, was advised at the time of its meetings, as Mr. Trotter said, that it was necessary to have concrete representations of these various standards; so to some extent we in England are independent of the questions, "What is the electro-chemical equivalent of silver, and what is the voltage of a Clark cell?" But I think we must go a little further than that, because, although these instruments are now independent of the fundamental units, they were not so originally.

Dr. Glazebrook.

The ohm standard, I mean the actual wire coil that Mr. Trotter has in his possession, was calibrated by myself, when made, to represent, as closely as I then could attain, a resistance of 106·3 centimetres of mercury under certain conditions; and although nothing is said in the Order in Council itself about again comparing that standard with the mercury column, yet in the resolutions of the Report of the Committee on which the Order in Council is based, there is a very distinct and clear statement that a material standard constructed in a metal should be adopted as the standard ohm, that is the coil, and "should from time to time be verified by comparison with a column of mercury of known dimensions." To that extent, then, the column of mercury was brought in as a kind of check on variations of this standard ohm. So, too, if one goes to the ampere balance, which is now in England our standard of current, this was originally based on the electro-chemical equivalent of silver. It is not an absolute instrument in the manner in which the new ampere balance that has been constructed from the designs of Professor Ayrton and Mr. Mather is an absolute instrument. Some few measurements of dimensions were made on the instrument of the Board, and certain approximate calculations were made when it was being constructed in order to see that the weight required would be approximately what was convenient; but beyond that the ammeter is not an absolute instrument, and depended originally on the electro-chemical equivalent of silver. With regard to the voltmeter I am not quite so clear, but if my memory serves me, it was originally calibrated by the aid of a battery of seventy Clark cells. Perhaps Mr. Trotter can correct me if I am wrong.

Mr. Trotter.

Mr. TROTTER: There were sixty-nine or seventy-one Clark cells employed to fix the fiducial mark on the scale, and there is still a series of Clark cells in existence. But it was also verified by the 100 ohms passing through it.

Dr. Glazebrook.

Dr. GLAZEBROOK: I think in the original calibration the Clark cell did to that extent come in. That brings me to the point that I want to make. If these concrete standards that we have in England were universally accepted, and taken as the standards throughout the world, then for the practical purposes with which electrical engineers are concerned, the question under discussion would cease to have any very marked interest. But that is not the case. An attempt has been made to set up an ampere in Germany depending also on the electro-chemical equivalent of silver, but they did not use exactly the same conditions in their voltameter; and, in consequence, exactly the same result is not obtained. That is also more markedly the case with the standard of electro-motive force. Although as a matter of fact in Germany the standard of electro-motive force is derived from the ampere and the ohm, and not directly from the Clark cell, they have determined the electro-motive force of a Clark cell in terms of their standard, and have arrived at a different result, as was explained last time, to what we have reached here. The consequence is that the concrete standards that are being used now, and that are likely to be used in the future throughout the world, are not identically the same, or rather are not as

Dr. Glazebrook.

nearly as we can make them the same. The main object of our discussion, and of the Conference, which I hope will take place shortly, was to discuss this, and to secure means whereby a uniform set of concrete standards could be established and accepted not only in England but throughout the world; just in the same manner as the kilogram in Paris, or the platinum-iridium metre rod are now the accepted standards for mass and for length throughout the whole world, or, at any rate, where the metric system rules. With regard to the question as to whether the differences that have shown themselves are important to trade, that is a point that was brought very clearly before us at St. Louis by various speakers. As Mr. Trotter pointed out at the last meeting, the difference of 0·078 of a volt in the electro-motive force of a Clark cell is very small, but that does make a difference of from 0·4, as he said, to, I think, rather more than that, as much as 0·8 of one per cent. in the brightness of an incandescent lamp, depending upon the efficiency of that lamp. If the lamp is of low efficiency, then the effect is only something like 0·4; for a 2½-watt lamp the effect rises to 0·8. That is sufficient to make differences in the commercial sale and purchase of lamps. But although the effect on the candle-power of the lamp is comparatively small, according to the evidence that was brought before us at St. Louis, the effect on the life-efficiency of the lamp, the candle-hours output of the lamp, is considerably greater than that. The figures that were before us showed that the effect was something like 2 per cent.; and as Dr. Sharp told us, something like ten million lamps were sold in the United States last year subject to a guarantee that the life-efficiency came within certain definite values, such that 2 per cent. may bring many lamps outside the allowance, it was clear that a variation of 2 per cent. in the life-efficiency had a real commercial value in the States, and probably will in time have a marked commercial value here. Those are some of the reasons that have led to the resolutions that were accepted by the Congress, and to the desire that there should be at some time shortly in Europe an International Conference to discuss and consider these matters. With regard to the International Conference, I am in a position to say that His Majesty's Government are prepared to assist by nominating delegates to such a Conference, and I hope possibly by more active aid even than that. I am also able to say that the United States, the German authorities, the Italian authorities, and, I trust, the French authorities, will all give their adherence to such a Conference;* so that I think we may take it that the Conference that was asked for as a result of our discussion will certainly take place within the near future.

Professor Silvanus Thompson.

Professor SILVANUS P. THOMPSON: We have to thank Mr. Trotter very much for having cleared the air by the remarks that he addressed to us last week, insisting on the essential distinction between the "unit," which was a sort of definition, and the "standard," which represents in a more or less concrete form the legal realisation of that definition. I rise to point out that the question whether we ought to add another figure in the second or third place of decimals to the

* Since the discussion I have learnt that Sweden and Denmark wish to join.

Professor Silvanus Thompson.

value that we assign in terms of a column of mercury to the legal ohm or to the ideal ohm is not really so fundamental a question as this:— That if we are bound by any one of our three electrical standards, we have no need whatever to define as standards, except in a secondary sense, for purposes of convenience, the other two. I remember that one of the speakers last week pointed out that if we defined two of them that would necessarily settle the third. If we define, for example, the volt and the ohm, then the ampere follows as a matter of course; it being that current which the volt, as defined, will send through the ohm as defined. But this does not go quite far enough; for, as I shall presently show, if we settle one of them we have no choice; the other two are by that very fact settled. And it follows for this simple reason, that our units were originally intended to be part of a connected system, fitting on, through the magnetic unit, to the mechanical units that are internationally defined. We have not only an international definition of length in terms of the standard metre, and of mass in terms of the standard kilogramme, and of time in terms of the second, but by that very fact we have got our definitions of what must be taken as the units of velocity, of acceleration, of force, of power, and of work. However much we choose to change our ohm, or to change our ampere, or to change our volt, we cannot get rid of the fact that the horse-power is 33,000 ft-lbs. per minute in the latitude of London; we cannot get rid of the fact that the watt will still remain to be 10^7 ergs per second; we cannot get rid of the H.P. being 746 watts, if the watt is 10^7 ergs per second. Seeing, therefore, that the watt is defined by being absolutely deduced from the standards of length, mass, and time, whichever one electrical unit we choose we thereby settle the other two. Now this is very important, because it shows that we must not make the mistake in going into this question of the electrical standards, of setting up superfluous standards; because it is absurd to set up three standards where one suffices. Let me point out what has happened in the progress of history, and will happen again in future history. When we have once got a well-defined standard, whether it fits to the ideal unit or not, we shall continue to employ the standard, and, as a speaker expressed it last week, we shall "scrap" the unit. The metre was intended to be one ten-millionth part of the earth's quadrant. They measured the earth to the best of their ability more than a hundred years ago, and they made the metre a standard bar of platinum. More accurate measurements of the earth have shown that the metre is not exactly one ten-millionth part of the earth's quadrant. The earth has grown a little bit since then. There are meteorites falling on it every day and night, and I believe it will grow about one-eighth of an inch in diameter in a century, on account of the meteoric matter falling on it. But it contracts by cooling, and contracts somewhat irregularly, and therefore the earth is not a standard any longer. We have found that out since, but the metre remains to be our concrete standard. Now we have made an ohm. It has been in existence for a good many years. No one is more familiar with it than Dr. Glazebrook, and that ohm is a concrete standard. We were discussing last

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week whether that particular concrete standard, the ohm, is to be expressed as 106·3, or 106·34, or 106·28, or something or other, in terms of a mercury unit which nobody seems to be able to build twice over exactly alike. Clearly, what we have to do, if we have any historic sense, is to stick to the standard we have got, whether it fits to the ideal or not. What has happened in other cases? The original definition of the kilogramme was that mass of water which would fill a litre, that is to say, a cubic decimetre at a certain temperature. I am told by Dr. Glazebrook that the comparisons of recent date made between the actual platinum kilogramme and the actual metre show that it very nearly does that, perhaps to within $\frac{1}{100000}$ part, but it does not do it absolutely and exactly. Take a case nearer home—if I am wrong Mr. Trotter will correct me. There are at least two Acts of Parliament which define the gallon. According to the one method the gallon is that volume which will hold exactly 10 lbs. of water at some particular temperature, and is declared to be 277·274 cubic inches. I believe the other Act of Parliament declares that the imperial standard gallon shall be 277¼ cubic inches—at least, we get that in the table-books. But then there is another decision—I believe it comes under the Weights and Measures Act, 1825—that the imperial standard gallon shall be a certain pot which exists in the bureau of the Board of Trade. I take it that it is the actual contents of that concrete standard that are the legal gallon in this country, no matter whether it is 277¼ cubic inches, or 277·274 cubic inches, or whether it will or will not exactly hold 10 lbs. of water. It does not matter what those ideal figures are. There is the gallon, a thing which can be handled, and we are bound by it, so far as we are bound by any gallon at all. We have to stick to standards when we have got them, and scrap our units if we find the standards do not exactly fit to the ideal. I take it, then, we have got such a thing as an ohm, and that we are rather doubtful about the ampere and the volt, and I hope that we shall remain doubtful about any standard of ampere and volt that does not fit to that which is already necessarily legal in this country. For, observe, it follows from the laws of energy that the volt is equal to the square root of the watt multiplied by the ohm ($V = \sqrt{W \times R}$), and that the ampere is equal to the square root of the watt divided by the ohm, ($C = \sqrt{W \div R}$). So if the watt is settled (in terms of the standard metre, and the standard kilogramme, and the second), and the ohm is a concrete settled thing, then the volt and the ampere follow suit; and the thing we have to do is to use as secondary standards for convenience the best instruments we can procure to read volts and amperes in accordance with them.

This brings me to another totally different point in the discussion on which I was specially asked to speak, but which did not practically enter into consideration last week at all; and that is on the system of units proposed by Mr. Giorgi. This system has been discussed largely on the Continent, and has been more or less dimly discussed in this country. It was put before the Congress at St. Louis. The account which Professor Ascoli gave, which is printed in the Report of the St.

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Louis Committee, is an extremely delightful exposition of this theory. I desire to state as strongly as I can what an extremely great advance has, in my opinion, been made in the simplest possible way by the proposals of Mr. Giorgi. He goes into the whole question of electro-magnetic units, and in particular to that curious difficulty about the 4π, which breaks out in our formulæ sometimes in one place and sometimes in another. It arises from the circumstance that we base our electrical units upon the unit of pole-strength, defined in the old-fashioned way by means of considerations and forces acting at a distance, the law of inverse squares, and the geometry of the sphere. We cannot help the fact that the sphere has 4π units of surface in terms of its radius as unity, and therefore we cannot possibly help 4π coming into our units as long as we base them upon that particular ideal unit of magnetism, the unit pole which repels another equal pole of the same kind, in air, at the distance of one centimetre with the force of one dyne. But are we compelled to take that magnetic unit which involves the 4π? Long ago Mr. Heaviside and Mr. Fessenden saw that we were not. Lots of people have seen that there were ways of getting over the 4π difficulty, but none of them have seen so very simple and clear a way as Mr. Giorgi has. I would ask you to read Professor Ascoli's exposition of Giorgi's system most carefully, because you will see how beautifully he has laid out the logical issue involved; but beware of two or three misprints in the Report. What it comes to is this. In making a consistent electro-magnetic system we start from the circumstance that our electric current and our magnetic circuit are interlinked with one another; and all that goes on in every motor, dynamo, and electro-magnet depends on the magnetic linkage between the magnetic circuit and the electric circuit. The amount of magnetism we obtain, for instance, in an iron ring depends on the circulation or linkage with it of amperes; and Giorgi very properly points out that we are illogical in talking about the "ampere-turns." The whole effect depends on making amperes to circulate around, or interlink themselves with the magnetic circuit. Why do we put the 4π in there, and talk about the magneto-motive force being equal to 4π times the ampere-turns, or 4π divided by ten times the number of ampere-turns? You know perfectly well that, for most practical purposes, in designing machinery the 4π difficulty has been thrown overboard long ago, and designers simply reckon the magneto-motive force in ampere-turns; or, Giorgi would say, in the total circulation of amperes around the magnetic circuit. Take a practical point. Practitioners have seen clearly that they can do without the 4π in the calculation—that the amount of magnetic flux, other things being equal, is proportional to the circulation in amperes, and they use that as their definition of magneto-motive force. What further conclusion does this involve? You will have to alter something if you are going to throw away the 4π. You will have to do without that particular ideal unit magnetic pole. We can get on very well without it. What Giorgi has found is this: that if we start simply from that most elementary point, the linkage of a current with magnetic circuit

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expressed simply in amperes without any 4π, we have not to change any single one of our practical units. We may take the standard ohm exactly as it is, and we may take the volt and the ampere which are logically connected with it as I have mentioned. We must then take as our fundamental units neither the centimetre nor the gramme, but the actual platinum metre and the actual platinum kilogramme, and we have the kilogramme-metre-second system of units, on one logical plan. The basis is no longer the imaginary permeability of air as unity, nor the 4π lines radiating out from the unit pole, but is simply the concrete ohm; with the logical ampere and the logical volt to follow. Therefore it must follow—a point really involving in itself a very great simplification in our ideas—that we may write the ampere as being not only the unit of electrical current, but also as the unit of magneto-motive force; and correspondingly we may write the volt not only as the unit of electro-motive force, but also as the unit of magnetic current—the rate at which quantity of magnetism changes. For $E = dN/dt$, just as $C = dQ/dt$. Each of those, of course, is a quantity divided by a time—the amperes are the coulombs per second; and the volts are the webers per second, if we define the weber, the unit of flux, as 10^8 "lines."

Electric current = ampere = magneto-motive force.
Electro-motive force = volt = magnetic current.

Then if we multiply our two equations together we have on the one side electro-motive force multiplied by electric current, which gives us the watt, and magneto-motive force multiplied by magnetic current, which also gives the watt; and the watt takes its place as it ought, as the unit of power and activity, not only as an electrical unit, but as a magnetic unit as well as a mechanical unit. You thus succeed in unifying your electric and magnetic quantities with the mechanical quantities, and *make no change whatever* in the ordinary practical units. All this is obtained by simply adopting that very elementary idea that the unit of magneto-motive force is simply the circuital ampere. I regard this as an extremely important simplification of our system of units; and as it leaves the standard ohm in the unchallenged position of being the one electrical standard that is necessary and sufficient, it is to be commended. It will, I think, commend itself to every one who is striving to obtain unity. We get an international standard in the ohm; whether we shall get international agreement on an imaginary or ideal ampere or volt or Clark cell no one can say. I beg those who are considering this from the high scientific point of view to pause before they saddle us with any new standard volt or standard ampere. The science that defies the practitioner will remain sterile; it will simply not be used. We have seen that again and again. But, on the other hand, it is equally important that practice should follow scientific lead, because the practice that defies scientific considerations not only inflicts a permanent injury on the electric industry in the long run, but also retards the progress of scientific investigation. If, therefore, we can agree on something, namely, the standard ohm as the electrical standard which fits in perfectly into the

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system of kilogramme, metre, and second, and define all the other electrical units on that plan, we have accomplished a great and important simplification, and one which marks a real step forward, both in practice and in theory.

Colonel Crompton.

Colonel R. E. B. CROMPTON, C.B.: Although I was one of your representatives at St. Louis, and was, and still am, much interested in the subject of this paper, unfortunately I did not take part in the discussion, as I was compelled to attend the discussions on standardising electrical plant.

Dr. Glazebrook in his remarks named me as one who has persistently urged the use of the Clark cell and a standard of resistance as the best means for the engineer to obtain accurate electrical measurements. In saying this he evidently referred to the fact that many years ago I foresaw the difficulty that was certain to arise in having three standards defined by the Board of Trade, not only the volt and the ohm, but also the ampere, derived not therefrom, but from the silver voltameter.

During the years that I have been working at this matter I have been endeavouring to perfect what Mr. Duddell has called tertiary standards, that is, the means by which we are able to transfer from the Board of Trade Laboratory, or the National Physical Laboratory, or from the Reichsanstalt, or any central laboratory which is custodian of the most correct standards, a sufficiently correct copy of those standards to our own test-rooms. I ask all in this room who are engineers to notice how little we are personally concerned with the minute correctness of the primary standards. These concern men like Dr. Glazebrook, and we have great confidence that they will obtain and keep them sufficiently accurate for our purpose; but it is no use their doing so unless we are able to transfer them with sufficient accuracy to our own test-rooms.

I disagree with Mr. Duddell when he states that an accuracy within half of one per cent. is sufficient for these tertiary standards. It is wholly insufficient. Such inaccuracy would be increased up to one or possibly one and a half per cent. in a power test, and would be likely to lead to endless disputes between consulting engineers, who have to pass our work as correct up to a certain standard of efficiency, and our own test-room people, who naturally believe their own standards to be very close to those at the Board of Trade or at Bushey. I think that you will find that the reason why I and others were compelled to develop these standards in the form of a unit of electro-motive force such as the Clark cell, and of a sub-multiple of the ohm so as to make our measurements of current by the "P.D." method, using the potentiometer, or, in some cases, a fine milli-volt instrument of the Weston type, is that such a set of instruments is very portable and not likely to be damaged in transit. If we used a standard of current it would be necessary for us to take backwards and forwards between the standards laboratory and our own test-rooms an ampere balance. An ampere balance, however, is a very delicate piece of apparatus, and no one could ever swear to its accuracy after it had been a journey by rail.

I am in complete agreement with Mr. Trotter, and have to thank him for putting so clearly before us the fact that whether the fundamental units are correct or not does not concern us in the sense that I have just now been discussing, and that what we really have to keep and refer to in case of a dispute between ourselves and the consulting engineers is the correct standards laid down by the Board of Trade. The correctness of the fundamental units only concerns us so far that any error will affect our measurements when we compare electrical power obtained by the volt and ampere with watts measured by mechanical means, such as the indicator diagram or the brake, and for this reason I think that Dr. Thompson is right when he points out that we must have the watt as correct as possible as a mechanical standard, and our tertiary ohm also a sufficiently correct copy of the one at Bushey, and that the volts and ampere standards that we keep at Bushey must be sufficient to enable the watt and ohm to agree, otherwise we shall be liable to get into the position which some consulting engineers put themselves into very frequently, that is, that they not only specify the means we are to use, but also the results we are to obtain, which is an impossible thing for any contractor to work to. Colonel Crompton.

Mr. H. E. HARRISON: After the very full discussion of these papers at St. Louis and the two discussions we have now had here, it is not so difficult to be brief as to find anything to say. Professor Thompson has further taken up the point, which was raised by Professor Ascoli, with regard to the 4π. I gather from Professor Thompson's remarks that he thinks the difficulty could be got over by altering our magnetic units. Yet I would remind him that, to take but one example, while the formula for the capacity of an ordinary plate condenser includes 4π, it has nothing whatever to do with unit magnetic pole. Should we, then, alter all our electrical units, or what should be done to get a consistent set of units without 4π? It seems to me the problem is one which it has been attempted to attack in two ways. One method may be called the algebraic, and consists in taking 4π from the side of an equation where it is a multiplier and putting it on the other side where it is a divider. Of course you may in this way get it in a less inconvenient place, but this does not make it disappear. Then there is another method, which is more of the nature of a geometrical attempt to get rid of the 4π. We have an example of this kind of thing, though not an electrical one, which is 300 years old, the attempt to flatten out a sphere, *i.e.*, Mercator's projection of the globe. Round about the Equator it is very much like the real thing; round about the poles it is not in the least like the real thing, it is a terrible distortion. Professor Perry has stated that he thinks 100 years hence people will wonder why we were so foolish as not to get rid of this 4π long ago. I do not at all agree with Professor Perry. I think that 100 years hence people will look upon Professor Perry very much as we now look upon those people who tried to square the circle 100 years ago. So much has been said about the distinction between units and standards that there is little more to be said, Mr. Trotter last time made the matter so exceedingly clear. What Professor Mr. Harrison.

Mr. Harrison.

Ayrton had to say about the ohm was rather a shock to many of us, but it emphasised the fact that we should have units which should be our ideals, and that our standards shall be, as far as we can get them, in accordance with the units, and that we shall for ever be trying to make our standards more and more accurate. If, however, we take our standards as our units, then we throw ourselves back at least 50 years, when I think I am right in saying there were standards, but no accepted units. It would be a step backwards, and one which ought not to be taken. The fact that it is inconvenient to keep on measuring up the world is no argument against our attempting to get better ohms and better standards generally. I was very glad indeed to hear Dr. Webster have the courage to say at St. Louis, in talking about the standards used for the different countries: "How much do they differ? Practically less than 1 part in 1,000. Now, I am very sure that I do no insult to any electrical engineer here present when I say that very few engineering measurements of any sort are at all influenced by an amount of 1 part in 1,000"; and any of us who know what commercial measurements mean will certainly agree with that. I fail to see the bearing of the effect of $\frac{1}{10}$ of a volt on the light of the lamp on which so much stress has been laid by Mr. Trotter and others. It is perfectly true that if you suddenly alter the voltage of an incandescent lamp by a very small amount you can see a jump in the light. But try this experiment. In a room lit by a single lamp get somebody to alter, or not to, without telling you which, the voltage by 1 or 2 per cent. while your eyes are covered. On looking at the light immediately afterwards you cannot tell whether the light has changed or not—at least I cannot; yet if the voltage were altered while you were looking at the lamp the change would be most marked, for a considerable percentage change is made in the light. Again, take two assistants, equally skilled in photometrical measurements, by how much can they measure the candle-power of a lamp? The personal errors are very curious; with two sources of light which are practically equal you know by how much those assistants will differ: with two very unequal ones you know they will differ by a great deal more. In considering the light of a lamp from a utilitarian point of view, surely an important factor is the eye. Regarding it as a philosophical instrument is a different thing altogether. The effect the lamp has on the eye is not dependent on $\frac{1}{10}$ of a volt, which need not be noted. Of course I do not mean to say for one moment that we should not get our standards as accurate as we possibly can. But, as Colonel Crompton has said, we may well leave Dr. Glazebrook to get his standards up to the utmost limit of accuracy, and all we need do is to send our standards to him to be checked from time to time; the slight changes that will be made in the national standards will make very little difference indeed to us from a practical point of view.

Mr. Crawley.

Mr. C. W. S. Crawley: I want to say a few words on behalf of the unfortunate workers for whose use the standards are supposed to exist as opposed to those who are only settling what they are to be. Professor Thompson has just put the necessity for permanence with his

Mr. Crawley.

usual clearness, and I am glad to find him on our side. He said, however, that only the ohm wants to be standardised, and the ampere and volt got at through the watt, but that only means standardising the ohm and watt instead of the ohm and ampere. What are wanted by the worker are definite standards of C, E, and R accurately correlated, and within, perhaps, 0·1 per cent. or 0·2 per cent. of their theoretical value. Our present standards are well within that mark; any further tinkering with them will be a very serious harm to every worker in this country, and of absolutely no corresponding benefit to any one of them. In a commercial test to an accuracy of 0·01 per cent. the commercial value of the result would not be affected if the standards to which it was referred were far more than 0·1 per cent. out. Suppose the next determination shows to absolute demonstration, and everybody accepts the fact that of our present standards R is right and C and E are both 1 per cent. high, *i.e.*, what we call an ampere is really 1·01 ampere. What is the result of leaving the standards unchanged? They are still correlated, *i.e.*, a volt still sends an ampere through an ohm, accurate to 0·001 per cent., or whatever the old figures may have been. So all electrical tests remain just as valuable as they were before, and capable of the same accuracy. In efficiency tests we should have learnt that when power was measured by C and E theoretical perfection was 98 per cent. instead of 100 per cent. We should still specify a machine to be 96 per cent. efficiency, and the maker would still supply the same machine as before. He would know, however, that he was only 2 per cent. instead of 4 per cent. from perfection.

On the other hand, if the correction is made in the standards, the new standard volt will send the new standard ampere through the ohm to exactly the same accuracy as before. But every ammeter and voltmeter in the country would be 1 per cent. wrong; every supply station would have to raise its declared voltage from 220 to 222·2 volts; every specification would have to be altered, and the grand result would be that the maker aforesaid would deliver the identical machine with the identical efficiency, only he would call it 98 per cent. instead of 96 per cent. What is in a name? Well, in this case the new name for the same old thing would entail tens or hundreds of thousands of pounds cost to the nation, not to mention moral and intellectual damages. Now we are not 1 per cent. wrong—in all probability we are not 0·1 per cent. wrong. And yet there is a talk of altering our standards. Granted the alteration will be so small that it will be contemptuously ignored by the workers: still they will all feel uneasy about their instruments, and when it comes to having machines rejected which would just have passed under the old standards, they will freely curse those who changed them merely for the sake of a name.

Professor Perry.

Professor John Perry, F.R.S. (*communicated*): We in England are all in substantial agreement. The most important thing before the St. Louis Congress was the fact that American legislators had not adopted the excellent resolutions of the Chicago Congress, and consequently it was now necessary to make new laws. England legislated in accordance with the Chicago resolutions, and new English laws are

Professor Perry.

unnecessary. The C.G.S. electrical units are absolute if the centimetre and gramme and second are absolute.

In America the legal volt is such that the Clark cell has 1·434 volts at 15° C. Here is their concrete standard, why do they want to alter it ? Simply because this never really was their recognised standard, nor ought it to be ; the only recognised standard is 10^8 C.G.S. units of E.M.F., which will be represented better and better as time goes on by one kind of cell or another. The legal units in England are specified in terms of C.G.S. units, but concrete standards are specified, which are, however, only recognised by law as representing the true units to as good an approximation as is possible at the time. Now that the Clark cell is known to be rather 1·433 than 1·434 volts, there is no difficulty in making a change in our standard of E.M.F. If we legalise the ohm at 10^9 C.G.S. units of resistance, the ampere at 10_{-1} C.G.S. units, the volt at 10^8 C.G.S. units, it seems to me that we are always safe in using all three concrete standards of r, C, and v, because it is known that they must all be slightly wrong, and that as time goes on we shall have the true units more and more accurately represented.

It is very curious how Dr. Wolff condemns our action, although clearly before him is the fact that it has saved us from the American difficulty. He and others argue in this sort of way : The metre was made to be the ten-millionth part of the earth's quadrant ; after it was made and legalised it was found not to be what was intended, but for all that the concrete unit was retained and is the absolute unit. So also with the kilogramme. Hence we ought to settle on concrete units of r, C, and v, and legalise two of them.

The mere fact that even Dr. Wolff sees that it is wrong to legalise *three* of them ought to have shown him that we cannot legalise any of them. A concrete volt is already legalised in America, why not keep to it ? Simply because it is wrong—and why wrong ? Because the real standard is not this concrete volt, it is 10^8 C.G.S. !

The metre was retained although it is not the ten-millionth part of the earth's quadrant. Why ? Because this ten-millionth part of the business was quite *unessential*.

Why is not the American legal volt to be retained ? Because it was meant to be 10^8 C.G.S. units, and is found to be wrong; the 10^8 business is *essential*. All through Dr. Wolff's paper he wonders at the want of logic of people who use the metre or kilogramme as absolute standards, and who refuse to use the electrical standard units as absolute. He will not see that it is hopeless to get different countries to agree in a matter like this, although he knows that their national laboratories will certainly go on trying to make concrete standards more and more in harmony with 10^9, 10^{-1}, or 10^8 powers of the units based on the centimetre and gramme. But even if America were alone in the world, Americans would change from 1·434 to 1·433.

I am glad we are not asked to discuss Dr. Kennelly's paper on the names of units. I am heartily in accord with the report of our own committee (I.E.E. Journal, vol. 34, p. 172).

Professor Ascoli is altogether in favour of the rationalised system of

Professor Perry.

Professor Giorgi. I would call Professor Ascoli's attention to a document sent by Dr. Glazebrook to the *Electrician* newspaper, and published July 31, 1891. This document describes what is in all essentials the Giorgi system, and its author had cautiously brought it on several occasions to the attention of the B.A. committee. Criticism was asked for from readers of the *Electrician*, but there was no criticism and the matter dropped. The system retained the ohm, ampere, volt, coulomb, farad, second, watt, joule, henry, etc.* 10^8 C.G.S. units of magnetic flux was the practical unit to be used in all equations in which volts, amperes, and ohms were used. Ampere turns were magneto-motive force without any multiplication by $\frac{4\pi}{10}$.

As a matter of fact, in the Giorgi system, or my system, as I might call it, the 4π, or $4\pi/10$, is simply shunted somewhere else; that is, the permeability of the ether or air, instead of being 1 is $4\pi\ 10^{-7}$ or $4\pi\ 10^{-9}$, or some other uncomfortable number. In fact, although in mere algebra, the 4π is not seen, it is really used in all calculations. This system was recommended for adoption by the A.I.E.E., March, 1900.

It is to be observed, however, that these units of Professor Giorgi and myself are not rationalised as Heaviside wants them to be, and as I think they ought to be in spite of all temporary difficulties. Heaviside wishes to shunt 4π out of all our work. (Incidentally he would use only one power of 10, say 10^8, to connect the practical and the C.G.S. systems, instead of our 10^9, 10^{-1}, 10^8, etc.) He would shunt it to a part of theory where no practical calculations are ever made, a place of obscure academic unimportance, namely, *point centres* of electricity and magnetism. His rationalisation would be as great a service to electricity as the change from HO to H_2O, etc., was a service to chemistry; troublesome at first, no doubt, for every one of our units, C.G.S. and practical, would have to be changed. I have always advocated the change. It must be made some time; it ought to be made now. There would be a year or two when the old and new amperes, volts, ohms, etc., would exist side by side—a sort of thing we are not unaccustomed to. There would be new graduations of instruments and new resistance boxes, etc.—but the 4π would have vanished for ever and thought would be simplified.

I should like to take part in an Electric Congress to consider this matter. It has never yet been carefully considered. I would advise everybody to read Heaviside's Appendix on Rational Units, in vol. ii. of "Electromagnetic Theory" (p. 275).

* *Extract from Memorandum* (*Electrician*, July 31, 1891): If my system is adopted—

1. A wire 1 cm. long moving at 1 cm. per second across unit field generates an E.M.F. of 1 volt.

2. If a wire 1 cm. long conveys 1 ampere, the power used (or developed) in moving it across the unit field of 1 cm. per second is 1 watt.

3. A magneto-motive gradient of 1 ampere turn per cm. produces unit induction per sq. cm. if the permeability is 1.

4. Change of induction at the rate of 1 unit per second produces 1 volt per turn of wire.

I pointed out how easy it would be to use inches instead of centimetres.

Professor Perry.

The question of Clark or Weston cell, *Zn* or *Cd*, we must, I think, allow men like Professor Carhart and Dr. Glazebrook to settle.

I would suggest in any new legislation :—Define in C.G.S.; but there shall be a legal standard kept whose value in C.G.S. shall be stated from time to time with greater and greater accuracy in accordance with the views of an International Commission which ought to meet occasionally.

Mr. Rennie.

Mr. J. RENNIE (*communicated*): Before taking part in this discussion I wish to make it clear that my remarks are not to be understood as representing the official views of the Board of Trade.

When the publications issued in connection with this discussion first came under my notice, the words "so called," which appear in the title of Dr. Wolff's paper, induced a mild shiver. Was the hand of the spoiler to be laid on the venerable C.G.S. system ? But a little further reading removed that fear. One realised that it was merely a sly hit by the author at the reputation which has been *conferred* upon us by our cousins on the other side of the Atlantic. Caution, conservatism, if you will, becomes objectionable only when it prevents progress, and we are still without any evidence that electrical measurement can be best promoted by an absolute relinquishment of the C.G.S. system.

There is a haste which produces anything but real progress, and the present question might probably never have arisen, certainly not in its present form, if our American friends had been a little more cautious in pinning their [legal] faith to the Clark cell.

There seems to me little doubt that the great wealth in facility of measurements which characterises the electrical industry as compared with any other, is traceable directly to our system of units and standards, and this again is undoubtedly indissolubly bound up with the C.G.S. system.

We are asked to believe that two important conditions attaching to standards are portability and range of measurement. One cannot help thinking that there has been an utter forgetfulness of the function of a standard in putting forward these two qualities as essential conditions.

It is difficult to realise the response which Mr. Chaney would give to a request "That his standard yard was required to verify an account for carpet" ; and "Would he kindly despatch by parcel post his standard pound for the purpose of settling the accuracy of pounds of tea ?"

In this connection it is somewhat amusing to read in a publication issued by the Bureau of National Standards, the extraordinary care that was taken with what is termed the "U.S. Prototype Meter No. 27." We are gravely informed that while crossing the Atlantic it was under the care of a special messenger, who was required to give a signed guarantee that while in his charge the apparatus had not been subjected to undue mechanical or thermometrical disturbance, and so on. Really, we cannot accept this condition of portability as being seriously put forward.

As to range of measurement, it need only be remarked that here questions of legal custom will seriously interfere with

Mr. Rennie.

the use of a standard constructed for a "wide range of measurement." It has become the universal practice amongst countries with whom standards have been a matter of concern for scores of years to restrict one particular piece of metal or apparatus to the representation of one particular and definite standard, whether it be length, weight, or other; and it is easy to see that the "wide range" proposal would produce endless legal trouble.

Previous to August, 1892, it had been the custom, in this country at least, to speak of the mercury ohm as "A column of mercury at O° C., having a certain cross-sectional area uniform throughout its length, and having a length stated in centimetres." Reduced to figures, this became "A column of mercury at O° C., having a cross-sectional area of one square millimetre, and a length of 106 (or 106·3) centimetres." In effect this meant that the *volume* of the mercury constituting the ohm was stated as the result of experiment, the cross-sectional area having been assumed.

At the B. A. Meeting in Edinburgh in 1892 this definition was changed; the statement of the cross-sectional area was dropped, the statement of length was continued, and to complete the definition the quantity of mercury constituting the ohm was defined by weight. A search among the available sources of information has not revealed any statement with regard to the density of the mercury, and it is obvious that in the change from definition by volume to definition by weight, some value for the density must have been assumed. It might, therefore, be advisable at the present moment, when the whole question is being revised, to have the past history in this matter made clear by placing on record the figure used for the density.

There is another matter in the same connection to which I would wish to draw attention. At the meeting to which I have already referred, two values, being results derived from experiments, were universally accepted in connection with the definition of the ohm. One was 0·9866 as the value in ohms of the B. A. Unit, the other was 0.9535 as the value in B. A. Units of the Siemens unit. Obviously these two give all the information necessary for the definition of the mercury ohm, provided we had an assumed value for the density of mercury, but besides those two accepted figures, two others were mentioned, both derived by calculation from the value 0·9535 already mentioned. These were 106·3 as the length of the mercury ohm, and 0·9407 as the value of the Siemens Unit in ohms. Calculating for the weight, using 13·595 as the density of mercury, and using 0·9866 in turn with each of the other three factors, we get values for the weight which range from 14·4515 to 14·4520, and for this reason it seems to me it would be advisable to place on record the full calculation by which the weight 14·4521 has been obtained.

For convenience of reference these figures are set out in the following table.

In any horizontal line the two values underlined are those from which the other values in that line are calculated :—

Mr. Rennie.

Value of B.A. Unit in ohms.	Value of Siemens Unit in B.A. Units.	Value of Siemens Unit in ohms.	Length of Hg. column for one ohm.	Weight of Hg. column for one ohm. $\Delta = 13{\cdot}595$.	Weight of Hg. column for one ohm. $\Delta = 13{\cdot}5955$.
0·9866	0·9535	$0{\cdot}9407_{23}$	$106{\cdot}30_{12}$	$14{\cdot}451_{65}$	$14{\cdot}452_{18}$
0·9866		0·9407	$106{\cdot}30_{38}$	$14{\cdot}452_{02}$	$14{\cdot}452_{53}$
0·9866		$0{\cdot}9407_{34}$	106·3	$14{\cdot}451_{49}$	$14{\cdot}452_{02}$

Recalling the remarks of Professor Ayrton earlier in this discussion, it might be observed that the change made in the definition of the mercury ohm has extended somewhat unwarrantably, I fear, the significant figure in the definition. Experimental results, as accepted, are stated to a value of, we may say, one in 10,000, and on this basis in stating the length a zero might be added after the 3, reading it 106·30. The weight, however, in the definition is stated to one in 144,000, being fourteen times the limit adopted in the experimental results upon which the whole definition is based.

When we come to the question of discussing a probable choice between the ampere and the volt as the second realisable standard, one must direct attention to the strange confusion apparent in Professor Carhart's paper where he speaks of applying a standard balance directly to the measurement of his cadmium cell. The discussion at St. Louis, and his paper, mentioned with high praise potentiometer arrangements for measurements. Certainly no one will dispute the extreme convenience of such a method, but the potentiometer and the standard balance are not of themselves sufficient to give a measurement of his cadmium cell in volts, and although merely repeating what was said at the beginning of this discussion with such powerful effect by Lord Rayleigh, I would recall the fact that such a measurement must necessarily include dependence upon the ohm. Why, then, should it not be sufficient to call the Standard Balance the realisation, and the secondary standard to be derived from this a statement of the electro-chemical equivalent of silver? This value is absolutely independent, and in that respect is preferable. The case for a substitution of the volt for the electro-chemical equivalent of silver seems to me to fail absolutely for this later reason. All the other arguments brought forward in its support are of quite secondary importance, and even if they were all accepted, which I scarcely think possible, they would yet be insufficient.

Professor Robertson.

Professor D. Robertson (*communicated*): I am strongly against arbitrarily giving the names of great scientists to any of the C.G.S. units. It is idle to propose such for any except those units in every-day use, as no one would remember them for any others. Besides, the only such names that have hitherto received general adoption belong to the practical system, and it would only lead to confusion to have similar names for C.G.S. units. I am also of opinion that no further names are

Professor Robertson.

required in the meantime for the practical system, as all are easily provided for by combinations of the names already adopted—*e.g.*, Volt-second, Ampere-turn.

I also advocate the adoption of either the Metre-Kilogramme-Second-Ohm system proposed by Giorgi, in which electrical resistance is taken as a fundamental quantity with the ohm, defined in terms of a mercury or wire standard, as unit, or else the taking of Electricity itself as the fundamental, with the Coulomb, defined from the electrolysis of silver, as unit, giving a Metre-Kilogram-Second-Coulomb system. The other electrical units should be *defined* in terms of the chosen one of these two, and the mechanical units, and "*represented* near enough for practical purposes" by the Board of Trade standards. The former system has considerable advantages owing to the accuracy and ease with which resistances can be compared. The latter has the theoretical advantages that there would be no fractional indices in the dimensional equations of the derived quantities, which fact probably shows that electricity has a better right to be considered as fundamental than either resistance, permeability (as in the electro-magnetic system), or dielectric constant (as in the electro-static system). The difference between the two systems would only be one of definition, except in the most accurate work. It would be advisable to adopt a value for the constants of vacuum in terms of the chosen units. That for the permeability could be adopted at once, since the ratio between the International Ohm and the C.G.S. unit is known with considerable accuracy from experiments by the Lorentz apparatus. The dielectric constant is not known with the same accuracy, but it is of less importance.

I am sorry to note that the Electrical Standards Committee have expressed a leaning towards the C.G.S. system. There seems to be an idea in some quarters that this system has some inherent advantage, and even that it is "necessary" for theoretical work. The only advantages that one system can have over another are that its standards are more reliable, more easily copied, and more universally known, and that the units themselves are of more convenient magnitude. The K.M.S.O. system certainly possesses these in at least an equal degree with the C.G.S. In fact, the actual material standards to which the latter is referred do really belong to the K.M.S.O. system, which is the only one which has been legalised.

It only causes needless confusion and trouble to have two systems of units. Hence, either the C.G.S. or K.M.S.O. system must in time give way to the other. It will be impossible to alter the legal units without much weightier reasons than can at present be shown in favour of the C.G.S. system. Besides, it is easier for scientists, who understand these matters, to change their system, than for the general public. Scientists ought, therefore, to recognise that the Practical System is already a *fait accompli*, and gradually fall into line with this system, using, of course, multiples and sub-multiples when desirable with the corresponding prefix. Only those prefixes denoting powers of 1,000, however, should be employed, and it is probably better to use the

Professor Robertson.

index notation in writing. Thus "thousand" would be written 10^3, and read "Kilo," and so on for the others. The conversion of results already determined from the C.G.S. to the K.M.S.O. system would be an easy matter, as the change ratio would be simply a matter of ten.

The President.

The PRESIDENT : I now ask you to pass a vote of thanks to Mr. Duddell, who brought this report before us; and I think we may also thank the various gentlemen who have spoken in the discussion, which has been extremely interesting.

The vote of thanks was carried by acclamation.

Proceedings of the Four Hundred and Twenty-fourth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 13, 1905—Mr. ALEXANDER SIEMENS, President, in the chair.

The minutes of the Ordinary General Meeting held on April 6, 1905, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members—
James R. P. Lunn.

From the class of Associates to that of Members—
Wyatt Meacher.

From the class of Associates to that of Associate Members—
James Lord. | Harold A. McGuffie.

Messrs. L. T. Healy and L. Gaster were appointed scrutineers of the ballot for the election of new members, and at the end of the meeting the following were declared to have been duly elected :—

ELECTIONS.

Associate Members.

Charles Vivian Scott Dickens. | John William Stelling.

Students.

Robert Barron.
Montague Hayes Bythway.
Richard Fleming Chaffer.
John D. Crawford.
William George Rankin Crow.
Frederick Habler Downie.
Joseph Elstone.
Clive Bredall Hobson.
Harold Church Holroyd.
George G. Mallinson.
Thomas Darey Nassau.
John Nelson Naylor.
Joseph Rowland Robinson.
Harold Thompson.
Arthur Everitt Val-Davies.
Harry Wadsworth.
Bruce Gordon White.

Donations to the *Library* were announced as having been received since the last meeting from Mr. B. A. Pilkington ; to the *Building Fund* from Messrs. C. Poulsen and W. W. Strode ; and to the *Benevolent Fund* from Messrs. A. Press and J. H. Wolliscroft, to whom the thanks of the meeting were duly accorded.

The meeting adjourned at 9.30 p.m.

The discussion on "Magnetic Units" was concluded (see page 24) and the following paper was read :—

THE ALTERNATING-CURRENT SERIES MOTOR.

By F. CREEDY, Student.

(*Paper read April* 13, 1905.)

Within the last few years, much attention has been devoted to various forms of single-phase commutator motor, in the hope of finding, in some of them, a solution of the problem of electric traction by alternating currents. One of the most successful of these motors appears to be the old-fashioned alternating-current series motor, which is now coming into commercial use for railway work.

The following paper is an account of some investigations carried out at the Central Technical College between March and July, 1904, which are intended to show the effect, on the performance of the motor, of varying the elements of the design.

I propose, in the first place, to deal with the theory of the series motor; next, I give an account of a series of experiments verifying the theory; and lastly, an account of some experiments on the commutation of these machines.

PART I.

THEORY OF THE SERIES MOTOR.

The simplest way to study the theory of the series motor is, as in the case of many other motors, by means of its circle-diagram. I describe below a circle-diagram which I worked out for this motor some time ago, showing very clearly the leading characteristics of the machine. This diagram may easily be deduced as follows:—

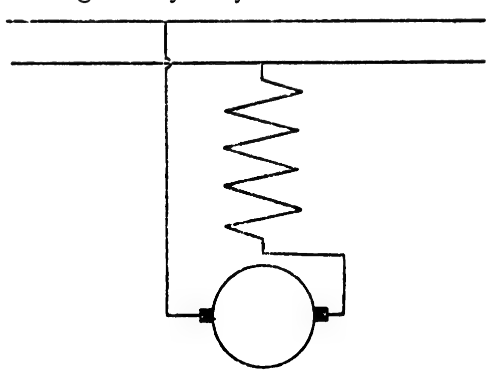
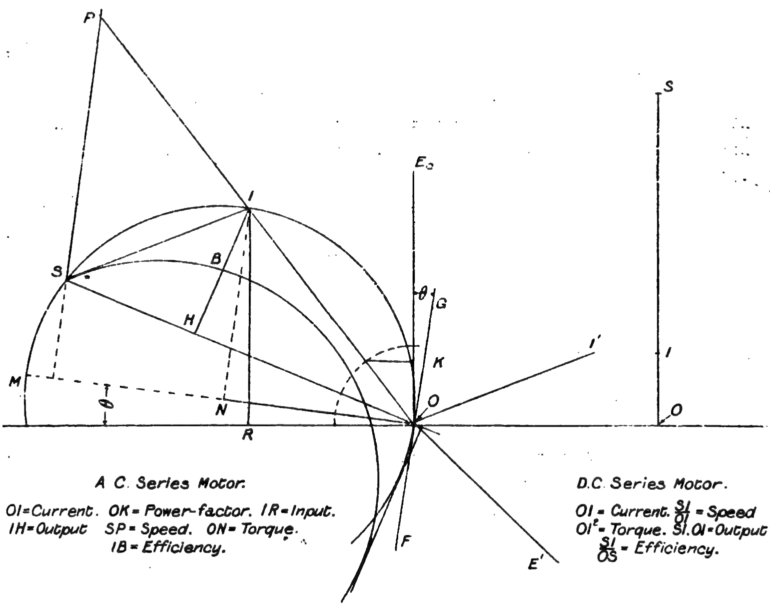


FIG. 1

The motor at standstill is a mere choking coil, and a current O S (see Fig. 2) will flow in it, such that the vector sum of all the E.M.F.'s in the circuit (the impressed E.M.F. and those induced by the current) is zero. Consequently if another E.M.F., such as the counter E.M.F. produced by the rotation of the armature, be applied to the circuit, it will produce a further current O I′ = S I lagging behind it by a certain fixed angle. The vector sum of this current and of the standstill current O S will be the resultant current O I. Now, since the counter E.M.F. O E′ of the motor is exactly in opposition to the resultant current, except for a small but constant angle due to the iron losses, and the current S I = O I′ lags by a constant angle behind it, S I must make a constant angle with O I, the resultant current. Since O S is constant and O I = O S + S I vectorially, O I must obviously move on a circle passing through the origin. In Fig. 2 the angle S I O is equal to the angle I O I′,



FIGS. 2 AND 2A.

since O I′ and S I are parallel. Now the angle between O S and O E_0 is the same as that between O E′ and O I′. Consequently, if θ is the small angle of phase difference between counter E.M.F. and current, and if O E′ leads O I by an angle $\pi - \theta$, O I′ will lead O I by $\pi - \theta -$ S O E_0. Thus—

$$\text{S I O} = \pi - (\text{S O E}_0 + \theta) = \text{S O F},$$

where the line F G makes the angle θ with O E_0; but, by Euclid, this is the condition that F G shall touch the circle at O. The diameter of the circle passing through the origin will, of course, make the same angle θ with the line of zero power-factor that the tangent does with O E_0.

Since S I is proportional to the counter E.M.F. of the motor, it must be proportional to the product of speed × flux, or, since the flux is proportional to O I, we have—

$$\text{S I is proportional to } s \times \text{O I or } \frac{\text{S I}}{\text{O I}} \text{ is proportional to } s,$$

where s stands for the speed of the motor. This construction for the speed may easily be simplified as follows :—

Draw a line S P, such that the angle O S P equals the angle S I O, and produce O I to meet it in P. The two triangles O S P and S I O will now be similar, since the angle O S P equals the angle S I O, and the angle S O I is common. Therefore $\frac{\text{P S}}{\text{O S}} = \frac{\text{S I}}{\text{O I}}$, and since O S is constant, the speed must be proportional to S P. Moreover, since O S P = S I O = S O F, as shown above, S P must be perpendicular to that diameter of the circle which passes through the origin. The torque, of course, is proportional to $(\text{O I})^2$. Since output = Torque × Speed, we have Output $= \frac{\text{S I}}{\text{O I}} \times (\text{O I})^2 = \text{S I} \cdot \text{O I}$. The following reductions of the torque and output constructions to a linear form I take from Blondel's paper on the series motor, in *L'Eclairage Electrique* last year.

Since the angle S I O is constant, the product S I · O I is proportional to the area of the triangle S I O, which is simply proportional to its altitude I H, since the base O S is constant. Thus we see that the output corresponding to any current may be represented by an ordinate I H, drawn from the point I perpendicular to the standstill current.

Also, since in a circle $(\text{O I})^2 = \text{O M} \cdot \text{O N}$ * where O M is the diameter through O, and O N is the projection of O I on it, we see that the torque is proportional to O N, since O M is constant.

Since we have Output = I H, and, obviously, Input = I R, we have Efficiency $= \frac{\text{I H}}{\text{I R}}$. This may easily be reduced to a linear form as follows :—

Draw a circle (see Fig. 3) equal in size to the current circle and with its centre C a fixed distance, measured along a line parallel to I R, below that of the current circle. This circle will cut off from I R a

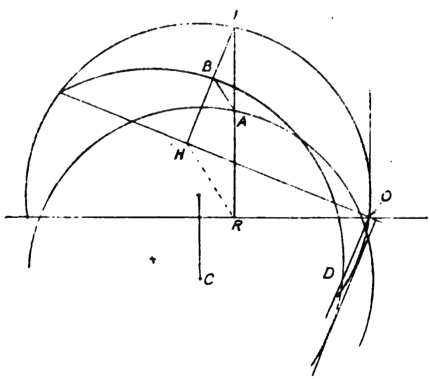


FIG. 3.

* A proof of this proposition will be given in Appendix I. The geometrical proof is as follows :—

We know that $(\text{I N})^2 = \text{O N} \cdot \text{N M}$. Add to both sides $(\text{O N})^2$. Then $\text{I N}^2 + \text{O N}^2 = \text{O I}^2 = \text{O N}(\text{O N} + \text{N M})$;

$$\therefore \quad \text{O I}^2 = \text{O M} \cdot \text{O N}.$$

distance I A equal to the distance between the centres of the circles. Draw through A a line parallel to H R cutting I H in B. Then $\frac{IB}{IA} = \frac{IH}{IR}$, and as I A is constant, I B measures the efficiency. Now the locus of B, as the speed varies, is very nearly a circle, there being one circle for every position of C.* This can easily be verified by trial.

Every such circle will pass through the point S and be tangent to a line drawn perpendicular to O S, and touching the current circle at a point near the origin. These conditions enable us to draw in a suitable circle at once on our diagram. It will be proved below that O D (Fig. 3) represents 100 per cent. efficiency. This gives us the scale of the construction (approximately). Thus the efficiency is measured simply by the intercept, between the current circle and the efficiency circle, of a line drawn through I perpendicular to O S. It may be seen that the efficiency continually rises from standstill to infinite speed, so that when the power-factor is good the efficiency will be good also. Moreover, from the construction for the output it can be seen that when the power-factor is good the output, though past its maximum, is still large. These facts form the reasons why the series motor is so much superior to some other single-phase motors, such as the repulsion motor, in which, as the circle diagram shows, it is very difficult to get good power-factor concurrently with good efficiency. It should be noted that the efficiency used above is the Electrical Efficiency, account being taken only of those losses proportional to the square of the current, such as the eddy-current loss—in this discussion the loss by the short-circuit current under the brushes,† is considered as an eddy loss, —the resistance loss, and (roughly) the hysteresis loss due to the alternation of the flux. No account is taken of the hysteresis loss due to the rotation of the armature or of the friction and windage.

A diagram, similar in many respects to the above, which allows of a very interesting comparison between the two motors, may easily be deduced for the direct-current series motor. At standstill a current $OS = \frac{e_0}{r}$ if e_0 be the impressed E.M.F. and r the resistance of the motor, will flow through the circuit, the impressed E.M.F. being balanced by the resistance drop. Consequently, if another E.M.F., such as the counter E.M.F. e_1, of the motor, be applied, a further current $SI = \frac{e_1}{r}$ will flow in opposition to the current O S. Thus as the motor speeds up the point I moves from S, towards O, along the straight line O S (see Fig. 2A). For the same reasons as in the alternating-current motor, the speed is proportional to $\frac{SI}{OI}$ and the torque to OI^2. We also have Efficiency $= \frac{e_1}{e_0} = \frac{SI \times r}{OS \times r} = \frac{SI}{OS}$, which becomes unity or 100 per cent. at infinite speed when $SI = OS$. As in the alternating-

* The accuracy of this construction is discussed in Appendix II.

† This current is the principal cause of the phase difference between the current and the back E.M.F.

current motor, the output is a maximum when $SI = OI = \frac{1}{2} OS$. Thus we arrive at the well-known proposition that when the output of a direct-current motor is a maximum its efficiency is 50 per cent.

A similar investigation in the case of the alternating-current motor gives much more favourable results. In this motor the only E.M.F.'s in phase with the current are, $i\,r$ the drop caused by the various resistances of the motor, and $e_1 \cos\theta$ a component of the counter E.M.F.; θ will usually be so small that it can be neglected. Thus we can express the input in the form $i\,(e_1 \cos\theta + i\,r)$, since the above are the only E.M.F.'s that can consume power.

Now, since $i^2 r$ represents all the losses that we can take into account (see above), $i\,e_1 \cos\theta$ must be the output. Thus, as in the direct-current motor and in the synchronous motor, we have Output = Current × projection of counter E.M.F. upon it. Indeed, a proposition similar to this may be proved for any motor. Thus we get—

$$\text{Efficiency} = \frac{e_1\, i \cos\theta}{e_0\, i \cos\phi} = \frac{e_1 \cos\theta}{e_0 \cos\phi} \quad \dots\dots \quad (1)$$

where $\cos\phi$ is the power-factor.

Moreover, if z be the total impedance of the motor, we have $e_1 = SI \times z$ and $e_0 = OS \times z$, and therefore $\text{Efficiency} = \dfrac{SI \cos\theta}{OS \cos\phi}$. Thus, when the output is a maximum, the efficiency will be much greater than 50 per cent., because, owing to the phase difference between the current and the E.M.F., the power consumed will be much less than that consumed in the direct-current motor under similar conditions. At infinite speed, since $\theta = \phi$ and $SI = OS$, we get 100 per cent. efficiency, as in the direct-current motor. This, as was pointed out above, is the electrical efficiency only.

The fact that the efficiency is 100 per cent. at infinite speed serves to fix approximately the scale to which the constructions given above measure the efficiency and output; and also, if we know the speed scale, it will give us the torque scale. The values thus obtained, however, will be a little too high, for the reason mentioned above. Thus we arrive at the conclusion that by working well beyond the top of the circle in Fig. 2 we can get good power-factor, high efficiency, and good "weight efficiency." The next question which arises is how to design the motor so as to attain this end.

In the following investigation the resistance of the motor and the small angle θ between the counter E.M.F. and the current will be neglected.

Let n = number of turns on the field.

n_1 = " " " armature between brushes. Thus $4\,n_1$ will be the number of conductors on the armature.

s = speed in revolutions per second.

p = permeance of main magnetic circuit, or, in other words, the number of lines produced in it per ampere turn. If there are more than one pair of poles, p will be the sum of the permeances of all the magnetic circuits in parallel.

p_1 = permeance of the armature magnetic circuit.
ν = leakage coefficient.
f = frequency of supply in cycles per second.

Now, if we are to have good power-factor, etc., we must make the ratio $\frac{\text{S I}}{\text{O I}}$ (Fig. 2) large.

Now, S I is the current produced by the counter E.M.F.

$$\therefore \quad \text{S I} = \frac{\text{Counter E.M.F.}}{\text{Impedance}} = \frac{4 \times \text{O I} \times n p \times n_1 \times s}{2 \pi f \left(n^2 p \nu + n_1^2 \left(\frac{2}{\pi}\right)^2 p_1\right)} \quad . \quad . \quad (2)$$

as the counter E.M.F. is obviously given by the same formula as in a direct-current machine.*

The reactance of the field is obviously given by the expression $2 \pi f n^2 p \nu 10^{-8}$, since $n^2 p \nu 10^{-8} = \text{L}$, the coefficient of self-induction; but on account of the fact that the armature winding is not on a bobbin, as is the field, somewhat greater care is necessary in determining its reactance.

Let $a\ b$ (Fig. 4) be the line of the brushes, and $c\ d$ a line perpendicular to it.

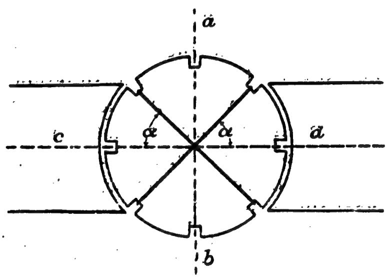


FIG. 4.

If we consider two turns, each making an angle α with $c\ d$, one on each side of the brush line, we see that the magnetising force in the direction $c\ d$, due to one turn, is exactly balanced by that due to the other. In the direction $a\ b$, however, the magnetising force of the two turns will be added. Since half the main current flows through each turn, the pair produce, in the direction $a\ b$, $i \sin \alpha$ ampere turns, where i is the current through the brushes. If for the sake of simplicity we suppose the winding evenly distributed, the ampere turns produced by the whole armature will be

$$i\, n_1 \frac{1}{\pi} \int_0^{\pi} \sin \alpha\, d\alpha = \frac{2}{\pi} i\, n_1.$$

Thus only $\frac{2}{\pi} n_1$ of the armature turns can be said to be active, and the reactance is therefore $2 \pi f \left(\frac{2}{\pi} n_1\right)^2 p_1$ or $0{\cdot}405 \times 2 \pi f n_1^2 p_1$.

Thus we see that $\frac{\text{S I}}{\text{O I}}$ is increased by—

(1) Raising the speed, if allowable.

* By taking p as constant, we are of course assuming that the iron is worked well below saturation, which is necessarily the case in alternating-current machines. $\frac{\text{S I}}{\text{O I}} = \cot \phi$ if we neglect resistance.

(2) Lowering the frequency. It will, as a rule, be much easier to design a satisfactory series motor for low frequencies than for high, though I believe it can be done for any frequency not much exceeding 50.

(3) By suitably designing the winding.

The expression for $\frac{\mathrm{SI}}{\mathrm{OI}}$ above will have a maximum for a definite value of n if we regard n_1 as constant. Differentiating with regard to n, equating to zero, and solving the equation thus formed, we get

$$n = \frac{2}{\pi} n_1 \sqrt{\frac{p_1}{p \nu}} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Substituting in (2) we get

$$\frac{\mathrm{SI}}{\mathrm{OI}} = \frac{4\, n_1^2 \sqrt{\frac{p_1 p}{\nu}}\, \frac{2}{\pi}\, s}{2\, \pi f \left(\left(\frac{2}{\pi}\right)^2 n_1^2\, p_1 + \left(\frac{2}{\pi}\right)^2 n_1^2\, p_1 \right)} = \frac{s}{2 f} \sqrt{\frac{p}{\nu\, p_1}} \quad . \quad . \quad (3\mathrm{A})$$

This expression obviously increases indefinitely with the decrease of p_1, and is independent of the number of turns on the armature. We also see that the maximum value of $\frac{\mathrm{SI}}{\mathrm{OI}}$ occurs when the field impedance is equal to the armature impedance.

Thus it is very important to make the permeance in the path of the armature flux as small as possible. The permeance of the main circuit should, as usual, be made as great as possible, and the magnetic leakage as small as possible. It is in order to make p_1 small that the alternating-current series motor is made with salient poles, like a direct-current machine, instead of being wound like an induction motor.

If the speed of the motor and the number of turns on the armature are constant, the counter E.M.F. will be proportional to the ampere turns on the field alone. Since it is in phase with the current, we may compare it to the resistance drop in the field, which is also proportional to the product of the current into the number of field turns (if the same size of wire is used throughout). This point of view enables us to consider the effect of varying the number of turns on the field in a very simple way.

Let r_0 be the "resistance" per turn $= 4\, p\, n_1\, s\, 10^{-8}$

$$\text{Then Efficiency} = \frac{i^2\, n\, r_0}{i^2 \left(r + n\, (r_0 + r_1) \right)}$$

where $r + n\, r_1$ is the total equivalent resistance of the motor and r_1 is the resistance of one turn of the field.

Cancelling out i^2, dividing by n, and putting $n = \infty$ we get

$$\text{Efficiency} = \frac{r_0}{r_0 + r_1}.$$

Thus we see that as the number of field turns increases, the efficiency at a given speed rises continuously.

The above investigations regarding power-factor and efficiency

become much clearer when regarded from a geometrical point of view (see Fig. 15), as is done in Appendix I.

Design of the Series Motor.

In designing a series motor the following information will generally be given:—

Output at full load ... ... $= W$ watts
Speed ... ... $= s$ revolutions per second
Power-factor to be not less than $\cos\phi$
Overall efficiency ... ... η
Impressed E.M.F. ... ... $= e_0$
Frequency ... ... $= f$

Let us first consider the design of a winding for a given carcase. We must first find the current at full load—

$$i = \frac{W}{e_0 \eta \cos\phi}$$

Next we must find the counter E.M.F. For the present purpose we may neglect the small phase-angle between current and counter E.M.F. We then have, from equation (1)—

$$\text{Electrical efficiency} = \frac{e_1}{e_0 \cos\phi}$$

This serves to determine e_1. The electrical efficiency must, of course, be estimated from experience. It should be possible to take account of a large part of the iron losses in it, but if this proves impossible they must be estimated in the usual way.

With this exception, those losses which are not taken account of in the electrical efficiency will be much the same as in D.C. machines, and thus experience gained with these would apply in estimating them.

We now have

$$e_1 = \frac{4 n_1 s i n p}{10^8}, \text{ or } n n_1 = \frac{e_1 10^8}{4 s i p} \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Since the magnitude and phase of e_1 are known, we can compound it with e_0 graphically and find the E.M.F. e_2 which actually causes the current to flow.

Now

$e_2 = i z$ or $\frac{e_2}{i} = z$, where z is the total impedance of the motor.

Neglecting, for a first approximation, the resistance of the motor, we have

$$\frac{e_2}{i} = 2 \pi f \left(p \nu n^2 + \left(\frac{2}{\pi}\right)^2 p_1 n^2_1 \right) 10^{-8} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

since $p \nu n^2 10^{-8}$ is the coefficient of self-induction of the field and $\left(\frac{2}{\pi}\right)^2 p_1 n_1^2 10^{-8}$ that of the armature, as considered before. From this equation, together with the one above, n and n_1 may be calculated.

Solving these two equations, we get

$$4\pi f p \nu \, 10^{-8} n^2 = \frac{e_2}{i} + \sqrt{\left(\frac{e_2}{i}\right)^2 - \frac{p_1 \nu}{p}\left(\frac{e_1}{i s}\right)^2 f^2}$$

and

$$4\pi f \left(\frac{2}{\pi}\right)^2 p_1 \, 10^{-8} n_1^2 = \frac{e_2}{i} - \sqrt{\left(\frac{e_2}{i}\right)^2 - \frac{p_1 \nu}{p}\left(\frac{e_1}{i s}\right)^2 f^2},$$

two formulæ which are not so formidable as they look.

It should be noticed that it will not be possible to fulfil the conditions given by equations (4) and (5) for all values of W, η, and cos ϕ. For instance, from equation (3A) we see that there is a maximum value of $\frac{\text{SI}}{\text{OI}}$, and therefore of cos ϕ, which is independent of n and n_1. If we assume cos ϕ greater than this, equations (4) and (5) will give imaginary values of n and n_1. Having roughed out the design in this manner, we may now check back, and introduce corrections, to take into account the resistance, etc.

We may, however, if we choose, take the resistance into account from the beginning. Although in a large machine this may not be necessary, in a small one it will be more important.

In order to take the resistance into account, all that we need do is to substitute the expression $\sqrt{\left(\frac{e_2}{i}\right)^2 - r^2}$ (where r is the total effective resistance of the motor) for $\frac{e_2}{i}$ in equation (5), and all succeeding equations.

We may easily determine r from the equation—

$$r = \frac{\text{Input} - \text{Elec. Output}}{(\text{Current})^2} = \frac{\text{W}(1 - \eta_1)}{\eta \, i^2}$$

η_1 being the electrical efficiency and η the overall efficiency. These formulæ furnish us with all that is necessary for designing a winding for a given carcase.

If, however, the carcase as well is to be designed, we must, of course, proceed differently. Having worked out the full load current and the counter E.M.F. as above, the next thing to do appears to be to settle tentatively the number of armature turns. In doing this three considerations must be taken into account: (1) the counter E.M.F. required, (2) the impedance of the armature, (3) the commutation of the motor.

It will be found that unless a very large and massive field magnet be employed, and also a very small air-gap, that it is practically impossible to obtain a strong flux. Thus, in order to get the required counter E.M.F., it will, in almost all cases, be necessary to use a large number of turns on the armature. It is important to notice that for a given current and given flux through a coil, far more E.M.F. will be induced in it, if the magnetic circuit has a low permeance, than if it has a high one. The reason of this is that we shall require a larger number of turns in the former case, and shall therefore get a larger E.M.F. of self-induction since this E.M.F. is proportional to the square

of the number of turns in a coil, while the flux through it is proportional to the first power only. Thus we see the importance of making p the permeance of the main magnetic circuit as large as possible. On account of the large number of armature turns which will, as a rule, be necessary, the impedance of the armature will be very considerable, unless we take very special precautions to reduce p_1, the permeance of the armature magnetic circuit, by thoroughly slotting the poles, and by using compensating coils. An example such as the one given below will convince one of the importance of doing this.

With a little previous experience of a similar machine, it would be easy to settle approximately the number of turns on the armature without much risk of error. Without this, however, all one can do is to work through various designs until one gets a satisfactory one. The considerations mentioned above may serve to some extent as a guide. Having settled the number of armature turns, we can find np from equation (4), and then n and p from equation (5).

It is of considerable interest to compare briefly the design of the alternating-current and of the direct-current series motor. In both machines the number of armature turns determines the flux, and the dimensions of the field magnet the number of turns which will be required on it in order to give this flux. In the alternating-current motor, as soon as we have determined these quantities, we have practically determined the impedance of the machine as well, according to equation (5). The resistance of the direct-current motor, on the other hand, is not determined by the numbers of turns on the field and armature, since it may be given any value, by putting sufficient copper on the machine.

Thus we see that in the alternating-current motor, since the impedance is determined by the number of field and armature turns, there are not so many independent variables as in the direct-current machine, and consequently the limits of good design are much narrower. With regard to the design of a carcase, I am at present unable to say much, since there was only one carcase at my disposal, and I was compelled to conduct all my experiments on that. The weak point of the above method of design, when we come to apply it to the design of a complete motor, is clearly the absence of any method of determining the self-induction of the armature from its dimensions. To calculate this self-induction rigorously seems impossible, and we must therefore have recourse to approximate formulæ, of the same nature as those of Behrend and Behn-Eschenburg, for the "dispersion coefficient" of the induction motor. To obtain such a formula it is obviously necessary to test many different machines. For instance, instead of the $\left(\frac{2}{\pi}\right)^2 p_1$ used in equations 2, 3, 3A, and 5, which is only the roughest of approximations, we should use an expression which will be a function of the air-gap, pole-pitch, shape and number of slots, etc., and should also express the effect of the compensating coils. The reluctance, and hence the self-induction, of the field, and the leakage coefficient, can easily be calculated by the well-known rules.

Example of the Design of an Alternating-current Series Motor.

In order to illustrate the method of design given above, I reproduce a design for re-winding the motor used in the experiments described below. On account of the unsuitability of the carcase, however, it is impossible to obtain very good results even at such a low frequency as 25.

Specification—

Output at full load	= 1 k.w.
Speed	= 2,000 r.p.m.
Power-factor	= 0·75
Electrical efficiency	= 70 per cent.
Impressed E.M.F.	= 100 volts
Frequency	= 25

$$i = \frac{1{,}000}{100 \times 0{\cdot}75 \times 0{\cdot}7} = 19 \text{ amps.}$$

$$0{\cdot}7 = \frac{e_1}{75}, \text{ therefore } e_1 = 52{\cdot}5 \text{ volts.}$$

Compounding e_1, with e_0 we get $e_2 = 64$ volts.

(It must be remembered that e_1 is *opposite* in phase to the current.)

$\therefore \quad \frac{e_2}{i} = 3{\cdot}37$ ohms, the permissible impedance of the motor.

As a mean of several sets of experiments on the carcase to be re-wound, we obtain $p = 290$ so long as the magnetic circuit remains unsaturated and,

$$\left(\frac{2}{\pi}\right)^2 p_1 = 60,$$

ν is practically equal to 1·24.

Thus we get

$$n\,n_1 = \frac{52{\cdot}5 \times 10^8}{4 \times 33{\cdot}3 \times 19 \times 290} = 7{,}180, \text{ about,}$$

and

$$3{\cdot}37 = 157\,(360\,n^2 + 60\,n_1^2)\,10^{-8}.$$

Since there are 36 slots on the armature, we are obliged to choose some value for $4\,n_1$, the number of conductors on the armature, which is divisible by 36. The most suitable value appears to be 504, which gives

$$n = 56 \text{ and } n_1 = 126.$$

These values will be found to satisfy approximately the above equations.

These values give—

Field reactance	= 1·75 ohms.
Armature reactance	= 1·49 ohms.
Total reactance of motor	= 3·24 ohms.

Since the armature impedance is nearly equal to the field impedance, we see that the power-factor is almost the best possible.

PART II.

Experiments on the Series Motor.

In order to verify the above theory, a series of experiments was undertaken, with the view of showing (*a*) the accuracy of the circle diagram described therein; (*b*) the effect of the number of turns on the field on the performance of the motor, and the fact that there is a certain number of field turns which gives a better power-factor than any other; (*c*) the effect of altering the number of turns on the armature; (*d*) the effect of altering the frequency; together with one or two other points of interest in this motor. The motor employed in these experiments was a small bi-polar overtype machine, with a double-wound armature having 36 slots and 36 commutator segments.

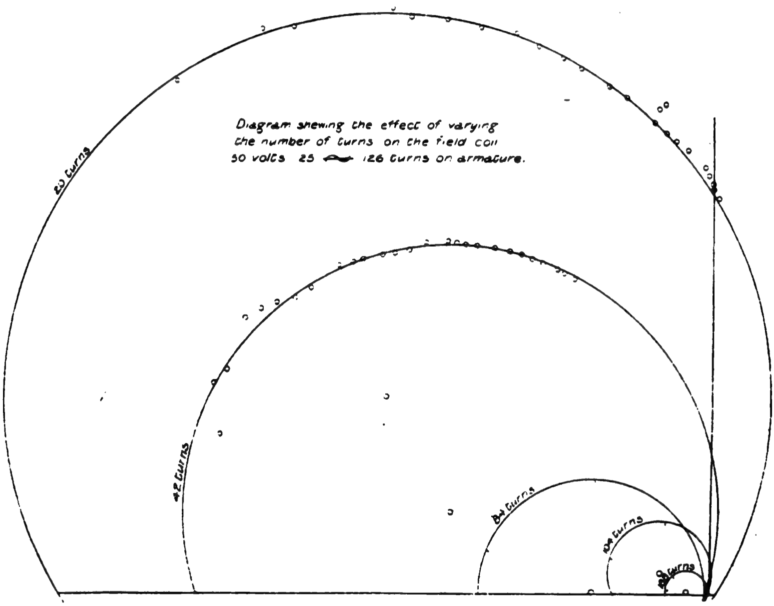


Fig. 5.

The double winding was intended to improve the commutation (which it did not do), and also to enable one to double the number of armature turns by simply altering the commutator connections. The field magnets were fitted with two coils, having 84 and 104 turns respectively. A connection was tapped off from the middle of the coil having 84 turns, so that 42 turns on the field were also available.

It was found, after some experiment, that the only available way of obtaining a reliable brake test was by using an electric generator as brake. As this machine was not always to be had, it was decided not to take any readings of output while investigating the methods of obtaining good power-factor, etc., but to make an independent investi-

gation as to the efficiency afterwards. Accordingly, while observing most of the curves below, readings of current, watts, and speed only were taken, the speed being kept constant in the following way. The pulley was fitted with a brake-strap, which was loaded until approximately the right speed was attained, when the final adjustment of the speed was made by altering the pressure on the brake-strap by hand. In this manner very good circles, such as those shown below, were obtained. A set of experiments was first made in order to show the effect of varying the number of field turns on the power-factor, etc. The result of these is shown in Fig. 5.

These curves were all taken at 25 frequency, and show the locus of the current-vector as we vary the speed, when we have 188, 104, 84, 42, and 20 turns on the field. The two upper curves were taken at 50 volts, so I have been able to put the points in. The others, however, were taken at a different voltage, so I have been obliged to reduce them to

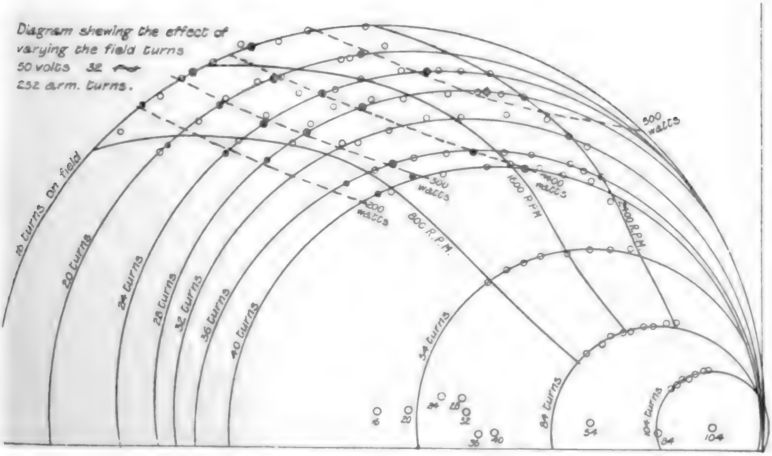


FIG. 6.

50 volts before putting them in, and have, therefore, merely indicated the range over which the observations extend. The points, however, lie as closely on the circles as do those shown. The curves show clearly the increase of the power-factor, at a given speed, as we decrease the number of turns on the field, and also, of course, the increase in the size of the circle. The range of speed over which the observations extended in all these and the following experiments was from 600 to 3,000 R.P.M. The curve corresponding to 20 turns, which shows such excellent power-factor, was obtained by putting the two field coils in opposition, there being a difference of 20 turns between them. The high power-factor is obtained largely at the expense of efficiency.

In the above set of experiments I was unable to reduce the number of field turns below 20, and thereby increase the current taken by the machine, for fear of burning it out. However, after the number of

turns on the armature had been doubled, and the armature impedance thereby quadrupled, some further experiments (see Fig. 6) were made which clearly demonstrate that if we decrease the number of turns below a certain point, the power-factor decreases. Thus we have shown experimentally that there is a certain number of turns which gives a maximum power-factor, as was shown theoretically above.

In order to verify the construction given in Fig. 2 for the speed, the distance S P (Fig. 2) is set out in Fig. 7 against the measured speed.

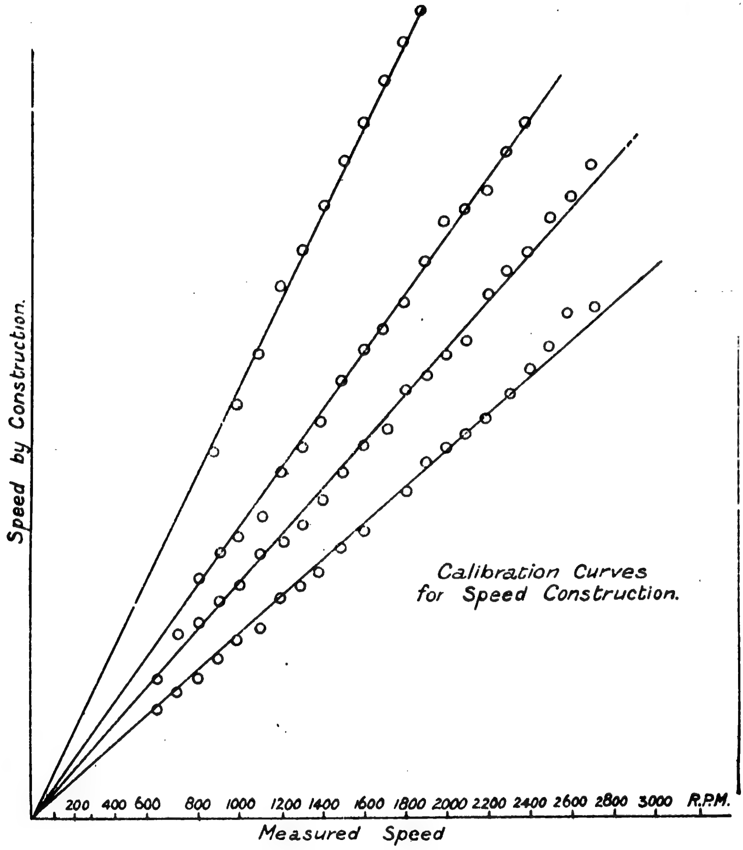


FIG. 7.

This is done in the case of the four circles corresponding to 20, 42, 84, and 104 turns respectively. In order to prevent the lines from coinciding, a different scale was taken for S P in each case. From these curves it can be seen how exactly proportional is the line S P to the measured speed. I have no doubt that equally good curves could be obtained from the other circles shown in the paper, but the four given seemed amply sufficient to establish the correctness of the speed construction, so no more were plotted. These curves, together with the

large number of experimental circles shown in Figs. 5, 6, 8, and 9, constitute a complete verification of the circle-diagram of the series motor, since the fact that the torque is proportional to the square of the current, so long as the magnetic circuit does not approach saturation, is self-evident. From the constructions for torque and speed, and that

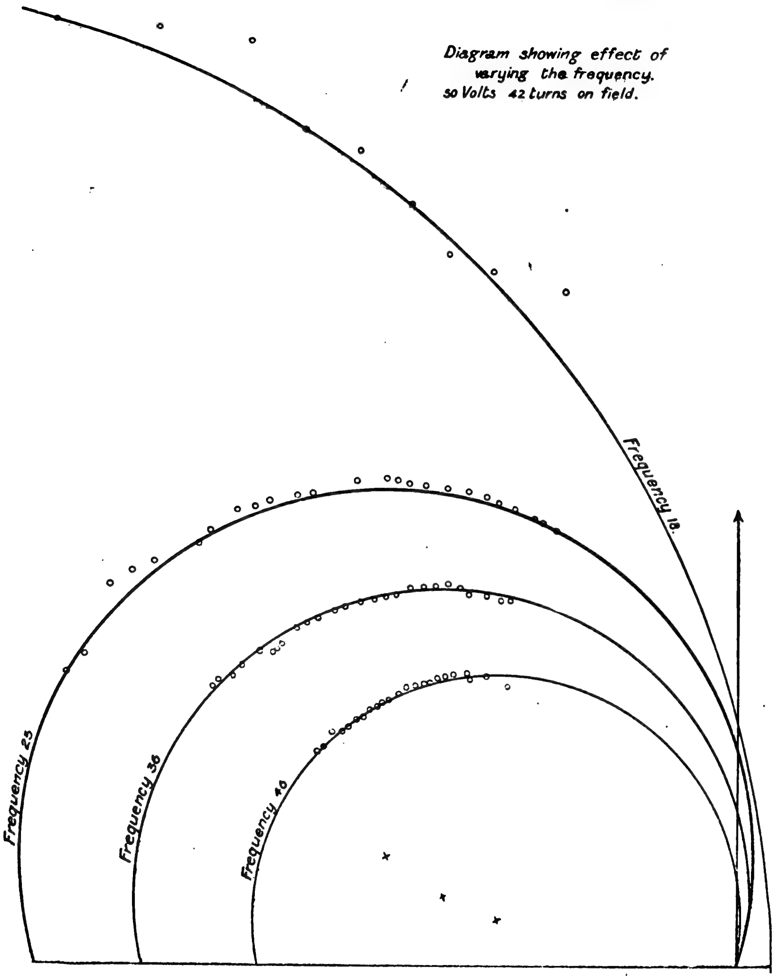


FIG. 8.

for the input, which also admits of no doubt, the constructions for output and efficiency follow immediately.

The next series of experiments made was intended to show the effect of varying the frequency, on the performance of the motor. The result of these is shown in Fig. 8. The increase of power-factor and of the size of the circle with decreasing frequency which theory leads

us to expect, is very well shown. The curves also show that as the frequency gets less, a given change in it produces a greater effect. This, of course, is no more than one would expect. The alteration in both power-factor and size of circle, when the frequency is reduced from 25 to 18, is very marked. The curve for 18 frequency was almost the only bad one obtained. It was several times repeated with the same results. The reason why it is so bad, is probably the excessive current taken by the motor.

In Fig. 9 are given two curves showing the effect of altering the number of turns on the armature.* The improvement in the power-factor thereby obtained is clearly shown, and also the decrease in the size of the circle due to the increased armature impedance.

In Figs. 10 and 11 are given some curves showing the effect of the number of field turns on the output and efficiency. These were taken

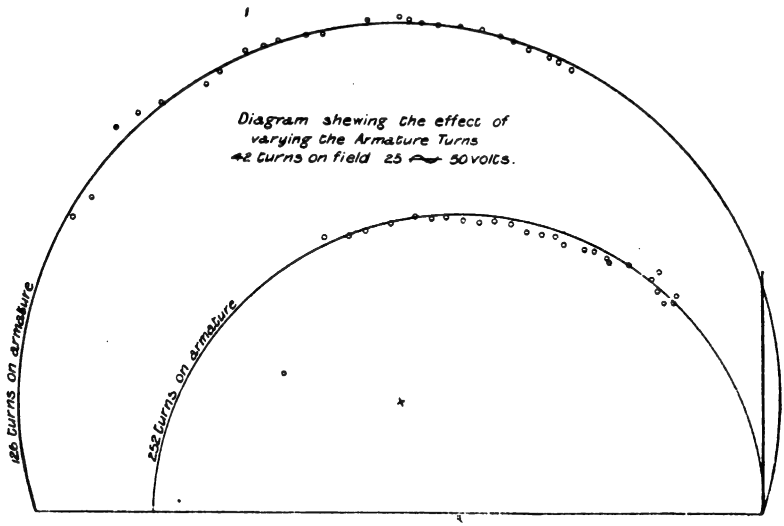


FIG. 9.

simultaneously with those in Fig. 6. Fig. 10 shows three efficiency curves corresponding to 20, 36, and 54 field turns respectively. These show that the efficiency at any given speed rises as the number of field turns increase, thereby agreeing with theory.

In Fig. 11 I have plotted the output against the number of field turns for various values of the speed. It will be seen that it appears to rise somewhat rapidly from zero to a maximum, and then to gradually decrease again with increasing number of turns. That the output must have a maximum is obvious, for it is zero when there are no turns on the field, and also when there are a great number. It must consequently have a maximum between these two points. The value of n

* When the number of armature turns is mentioned on the diagrams, the total number of turns is meant, not half this, as used in Part I.

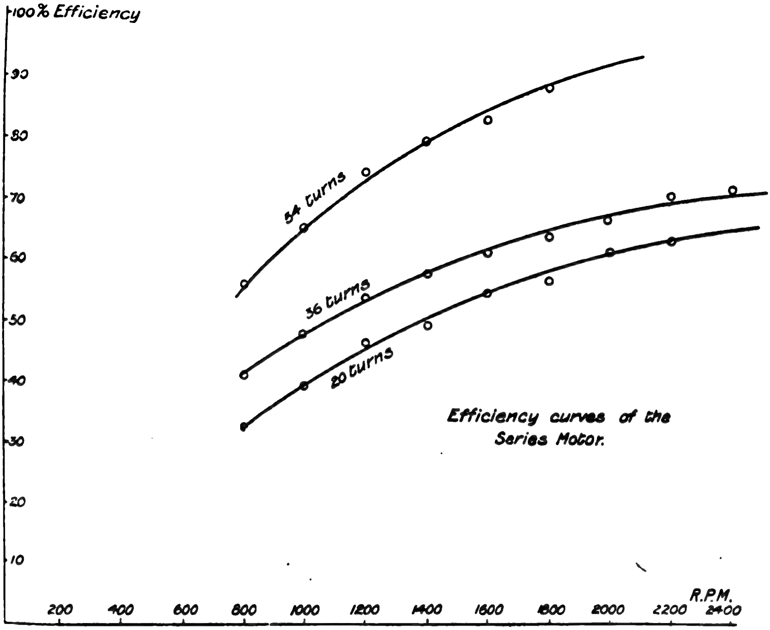

100% Efficiency
90
80
70
60
50
40
30
20
10
54 turns
36 turns
20 turns
Efficiency curves of the Series Motor.
R.P.M.
200
400
600
800
1000
1200
1400
1600
1800
2000
2200
2400

FIG. 10.

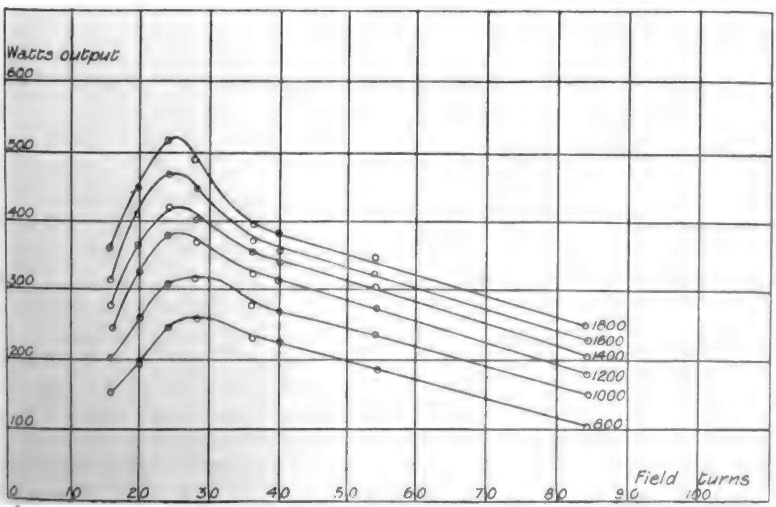

Watts output
600
500
400
300
200
100
0
10
20
30
40
50
60
70
80
90
100
Field turns
1800
1600
1400
1200
1000
800

FIG. 11.

for which this occurs was worked out mathematically, but the expression for it is so complicated that it seemed useless to give it.

In Appendix I. is given a diagram (Fig. 15) showing the various effects of varying the number of field turns in a series motor, while keeping the number of armature turns constant. Although Appendix I. was written after the experiments in Fig. 6 were performed, these latter fortunately enable us to verify this diagram almost completely. In Fig. 6 I have drawn in three lines of constant speed. The similarity in shape between these experimentally-determined lines and the theoretical ones in Fig. 15 is very marked. By plotting a series of curves of output against speed, for various numbers of field turns, and drawing lines through them corresponding to outputs of 0·2, 0·3, 0·4, and 0·5 k.w. respectively, I was able to ascertain the points on each circle corresponding to these outputs. These points are marked in Fig. 6 with a small circle with a cross inside. It may be seen, that if these points do not afford conclusive evidence that the lines of constant output are circles, they at least show that circles, such as are indicated by theory, serve to represent the lines of constant output remarkably well.

PART III.

COMMUTATION.

With the object of endeavouring to throw some light on the commutation of the alternating-current series motor, and the various other actions going on in it, a number of experiments relating to this subject were made with the aid of a Duddell high-frequency oscillograph, the curves being photographed on a falling plate. Many of the results shown below could obviously not be obtained on any instrument which records, not a single wave, but the mean of several. For instance, in the motor examined, no two commutation curves are exactly alike. A number of experiments was first made by the author, in conjunction with Messrs. R. S. Dahl and H. M. Lyons. In order to remedy some omissions in these, some further experiments were made later on by the author. As, during these experiments, the motor was fitted with very wide brushes, covering rather more than three segments, the experiments on commutation were repeated, as, owing to the long time of commutation, much better curves were obtained on the falling plate. In the discussion given below I have confined myself almost entirely to this latter series of experiments.

In observing the commutation curve of the motor the following method was made use of: The machine was fitted with two slip-rings, which were fixed on a piece of fibre and mounted on the commutator. One of these slip-rings was joined to a commutator segment, from which one of the armature connections had been unsoldered. This armature connection was then joined to the other slip-ring, and the brushes rubbing on these rings connected by means of a low resistance which served as a shunt for the oscillograph.

In Series A are shown a number of the commutation curves of the series motor obtained by the aid of this arrangement. Curve 1, consisting

Fig. 1.

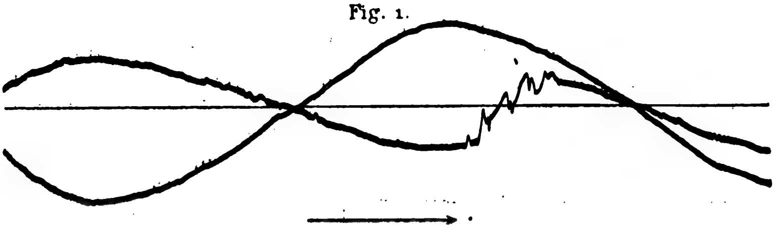


Fig. 2.

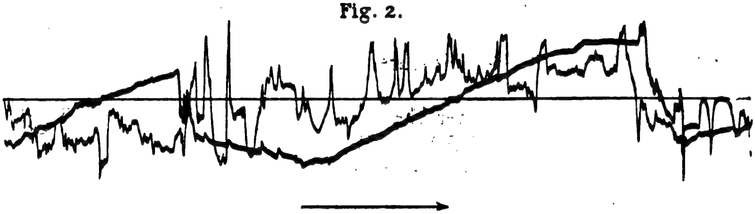


Fig. 3.

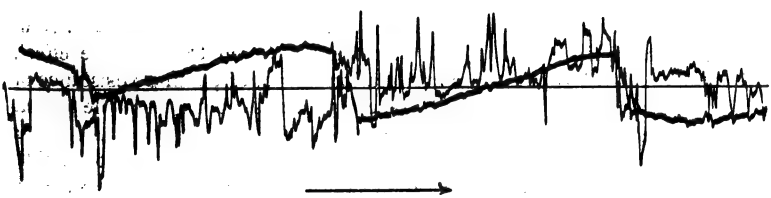
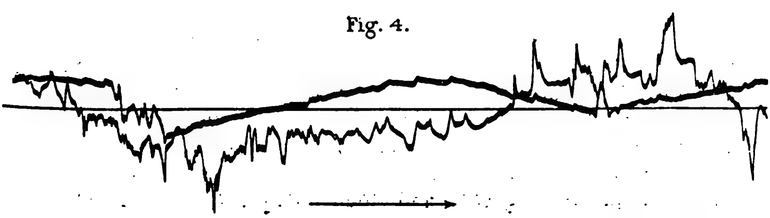


Fig. 4.



SERIES A.

of a curve of main current and of current in the armature coil, contains a very good example of the kind of commutation curve which is found in this motor. As it was thought that the ripples in the current during commutation might be due to the irregularities in the E.M.F. induced in the short-circuited coil by the main flux, a search coil of one turn was wound round the pole-tip, as shown in Fig. 12, as near to the armature as was practicable. Since the brushes are on the neutral line, the E.M.F. induced in this coil, due to the variation of the main flux, will be nearly the same as that induced in the coil under the brush.

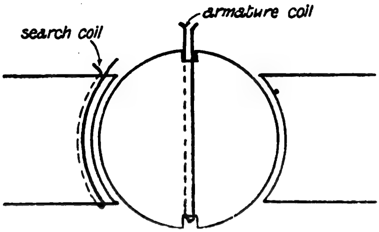


FIG. 12.

Curves 2, 3, and 4 (Series A) show the current in the armature coil, and the E.M.F. in the search coil parallel to it.

Curve 2 was taken under the following conditions: Main current 20 amperes, speed 1,000 R.P.M., frequency $26\frac{2}{3}$.

Curve 3 was taken under the same conditions, but at 2,000 R.P.M.

Curve 4 was taken with main current 17 amperes, speed 1,100 R.P.M., frequency 23. Resistance in circuit with the coil under observation $= 0{\cdot}3$ ohm. In the first three curves shown the generator used was a Wenstrom rotary converter.

In order to eliminate any possible disturbance due to the slots, commutator, etc., of this machine, in Curve 4 and all those succeeding, a bipolar Gramme machine, fitted with slip-rings and driven by a Westinghouse motor, was employed as generator. As this machine, of course, had a smooth ring armature, the effects of both slots and commutator were thus got rid of. Curve 4 was taken to show the effect, if any, on the shape of the commutation curve, of putting resistance in the armature coil. As may be seen, there is no appreciable effect. These four curves, if examined closely, seem to give us the cause of the oscillation in the E.M.F. curve. In all of them we may notice that there are small ripples in the current curves. These ripples are bound to cause corresponding ones in the E.M.F. curves, and, in fact, we notice that there does exist a ripple in the current curve corresponding to each of the principal ripples in the E.M.F. curve. This is especially marked in Curve 2. In order to show that very small ripples in a curve of current or flux are capable of producing enormous oscillations in the

E.M.F. curve, I give in Fig. 13 a curve of the E.M.F. induced in the
which coil, and underneath it a curve which is the graph of the integral
One of the .F. curve, and is consequently proportional to the flux pro-
one of the arm his curve was drawn by means of an integraph, the use of
connection was he drawing of these flux curves extremely easy, as it is
rubbing on these draw a point over the curve to be integrated, while
served as a shunt for egral curve. This method (viz., observing the
In Series A are show aph, and then integrating it mechanically)
series motor obtained by the

appears to be the only one by means of which curves of the instantaneous flux passing through a coil may be obtained.

The fact that the ripples in the current and E.M.F. curves do not in all cases exactly correspond is probably due to the fact that the current curves shown in Series A, do not represent the total current flowing round the field, but merely that flowing through one coil of the armature. A difficulty in the way of the above explanation, I must admit, is caused by Curve 1. This does show the current which passes through the field, and it shows no sign of any ripple. But how account for the indubitable correspondence between the current and E.M.F. curves if we reject the above?

A curve of E.M.F. in the search coil and of armature current was also taken with a direct current through the motor. It showed the same irregular ripples in the E.M.F. curve. Thus these cannot be connected with the fact that the motor is an alternating-current one.

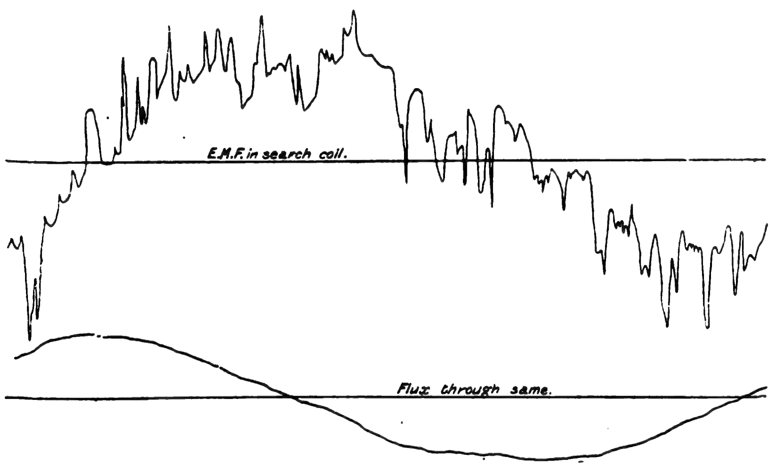


FIG. 13.

Curve 4 also shows us another interesting point. One of the commutations in it takes place at the point where the current is zero. We see that as soon as commutation begins there is a sudden peak in the current, and this in spite of the fact that there were 0·3 ohm in series with the coil under observation. I could reproduce, were it worth while, half a dozen different curves all showing this peak whenever commutation occurs while the current is zero. The cause of this is fairly obvious. If the current at all resembles a sine wave, its greatest rate of change occurs at the moment when it reverses, and consequently the E.M.F. induced in the short-circuited coil will be greatest at this moment.

From the nature of the ripples in the current curves they appear to be due to variations of the brush-contact or some such cause. We should therefore expect that both they and the oscillations in the E.M.F. curve would disappear at standstill. This was tried and found to be

the case, both being nearly sine curves. In order to make quite sure that the ripples in the E.M.F. wave were not due to the slots, the motor was driven externally and the brushes lifted. The E.M.F. curve was again found quite regular and devoid of ripples. The brushes were then put down, but were not connected to any external circuit. The result is shown in Curve 1, Series B. It may be seen that the peaks in the E.M.F. wave have reappeared, so that it seems as if some at any rate of the irregularity is due to the variation of the current in the short-circuited coil.

In order to endeavour to throw some further light on these variations, some experiments were made on a direct-current Westinghouse motor with laminated poles. A search coil of 13 turns was wound on the pole within $\frac{1}{2}$ inch of the armature, and the E.M.F. in it was observed—

(1) With the motor running light. The result is shown in Curve 2, Fig. B. It is, of course, very similar to that obtained by Dr. Thornton and described in his paper on "Eddy Currents." It contains a slow wave due to the eccentricity of the armature, which was very noticeable in this machine, and a ripple, due primarily, I think, to the slots. Most of these ripples have two peaks, though some have three.

(2) With the motor running light, but the brushes moved over so as to produce heavy sparking. The same ripples are noticeable, but one of the hollows in each seems to be exaggerated into a peak of large amplitude in the other direction, while one of the peaks is correspondingly exaggerated. Thus the E.M.F. makes a complete alternation between the main parts of each ripple.

(3) In order to find out whether the ripples in the two curves mentioned above are due to the slots or not, the Westinghouse motor was separately excited, run up to full speed, then shut down, the brushes lifted, and the plate taken while the motor continued to run on account of its inertia. The result is shown in Curve 4, Series B. The curve is very similar to Curve 2, but smaller. This is not due to a decrease of speed, for a comparison of the frequency of the ripples in the two cases shows that the speed was much the same in both. It still contains very sharp peaks, similar to those in Curve 3, but all on one side of the zero-line.

Thus it would appear that the armature current in some way reinforces these ripples and also damps out the sharp peaks shown in Curve 4. A confirmation of this view may be found in the fact that Dr. Thornton found that these ripples were smaller (in fact, he could not observe them at all) when the brushes were in the neutral position than when they were displaced. This certainly suggests the reinforcement of the ripples by the armature current. This may perhaps be explained by the action of the armature current on the fringe issuing from the pole-tip.

To sum up :—

The fact that we get the irregular-shaped E.M.F.'s shown in Series A. with D.C. as well as with A.C., and that no such E.M.F. occurs in the Westinghouse motor, justifies us, I think, in inferring that it is

Fig. 1.

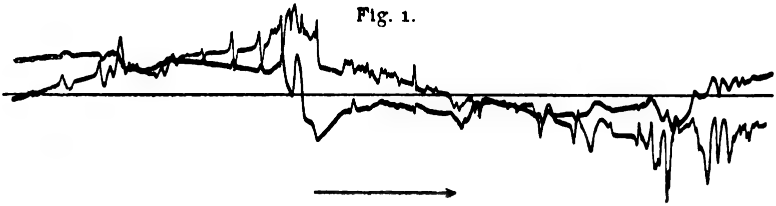


Fig. 2.

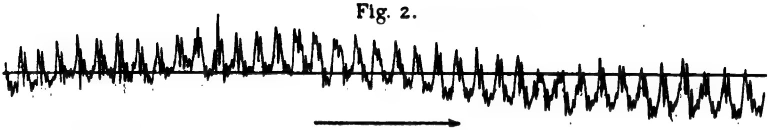


Fig. 3.

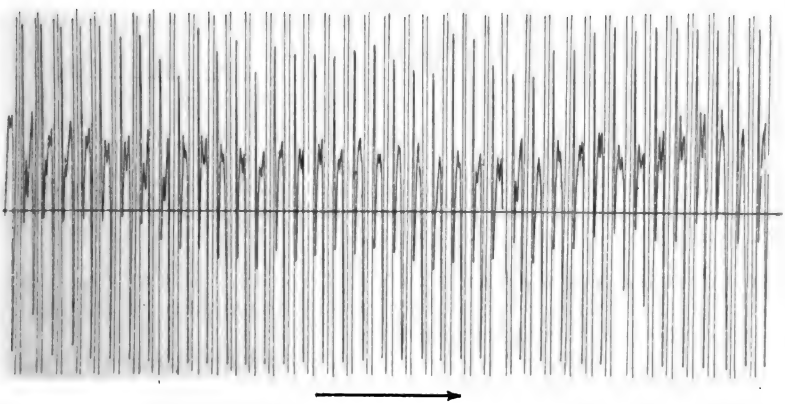
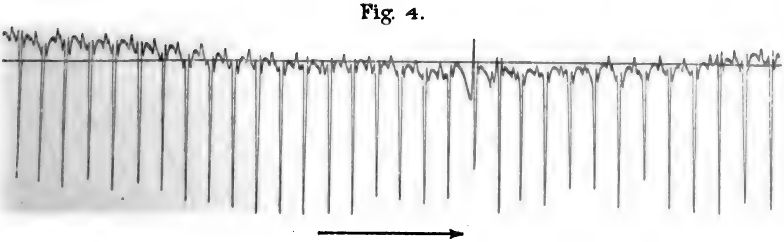


Fig. 4.



SERIES B.

peculiar to the motor experimented on. Moreover, the experiments described above definitely show that it is due to some action taking place at the commutator. It must be, I think, due to the fact that in order to get the current density in the brush low enough, I was obliged to use brushes of very large area, and thus, the brush-holders being intended for much smaller brushes, the pressure was insufficient and the contact uncertain.

In Fig. 14 are shown curves of main current and counter E.M.F. in the series motor. The motor was driven externally and the field excited with alternating current. This current, and the E.M.F. across the brushes (which were open-circuited except for the oscillograph connections), were then observed on the oscillograph. These curves show very clearly that lag of the counter E.M.F. behind the current which I mentioned in Part I. The ripples in the counter E.M.F. curve I am inclined to put down to the fact that the brush sometimes short-circuits three and sometimes four segments. When three only are short-circuited, there are more turns on the armature active, than when four are short-circuited. When these curves were taken the

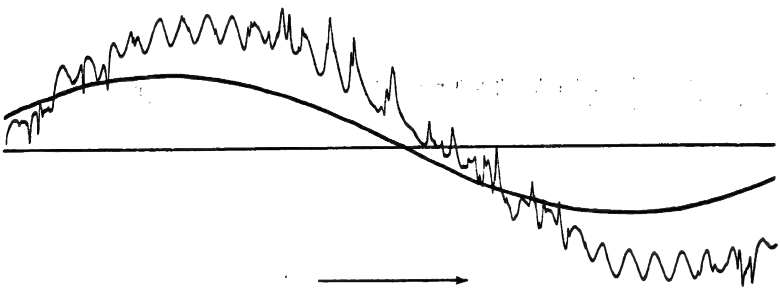


FIG. 14.

motor was running approximately in synchronism, and it may be seen that there are about 36 ripples per period—the number of the slots and of the commutator segments.

The above curves show something of the actions going on in an alternating-current series motor; but they afford no indication as to how to obtain good commutation. I found, however, that by using a very low current-density in the brush, and moderately hard carbons (not too hard), I was able to get perfectly satisfactory commutation, in the motor I used, with all frequencies up to 35, currents up to 30, and speeds up to 3,000. The irregular-shaped E.M.F.'s shown in Series A did not seem to affect the commutation.

In conclusion, I wish to express my thanks to Professor Ayrton and Mr. Mather, who have given me every possible assistance in carrying out the above series of experiments, to Mr. W. Cramp, and to the Crypto Works Co., the builders of the experimental motor. I wish also to express my thanks to those second and third year students of the Central Technical College who have assisted me in the above experiments, most of which required three observers. This assistance

I have received from Messrs. Montgomrey, Halse, Austin, Webber, Hanson, Gordon, Deakin, Harper, Tanaka, and Strickland.

APPENDIX I.

SYMBOLIC THEORY OF THE SERIES MOTOR.

The theory of the series motor is so simple that it can be treated by a geometrical method, as has been done above, without undue complication. In order, however, to bring out the analogy between the series motor and other motors whose theory is more complicated, and in order to deduce some results which do not come out easily by the geometrical method, I give in this appendix a discussion of the theory of the series motor by Mr. Steinmetz's symbolic method, the only method that can profitably be used when the theory of a motor presents any degree of complexity.

Mr. Steinmetz's methods are now very well known, so that I need not describe them. The idea of the "scalar part" of the product of two vectors, or their "scalar product," is also, I think, perfectly familiar. Thus all that is necessary is to show how this idea may conveniently be introduced into Mr. Steinmetz's method.* In the following discussion vectors will be denoted by thick black type, such as $\mathbf{i}$; quantities such as impedances, by small capitals, such as $\textsc{z}$; and numbers by italics, such as n.

Every vector $\mathbf{a}$ may be written $\mathbf{a} = a(\cos \alpha + j \sin \alpha)$, which may be abbreviated to $a \operatorname{cis} \alpha$. Here α is the angle between $\mathbf{a}$ and the real axis. By a well-known trigonometrical theorem, $\cos \alpha + j \sin \alpha = \varepsilon^{j\alpha}$.

Therefore $\operatorname{cis} \alpha = \varepsilon^{j\alpha}$.

Consequently by the laws of exponentials :—

$\operatorname{cis} \alpha \operatorname{cis} \beta = \operatorname{cis} (\alpha + \beta)$; $\operatorname{cis} \alpha / \operatorname{cis} \beta = \operatorname{cis} \alpha \operatorname{cis} (-\beta) = \operatorname{cis} (\alpha - \beta)$.

Thus the operator $\operatorname{cis} \theta$, simply turns a vector through the angle θ, counter-clockwise or clockwise, according as θ is positive or negative.

Now the scalar product, or the scalar part of the product, of two vectors $\mathbf{a}$ and $\mathbf{b}$, is the product of the length of either vector into the projection of the other upon it, *i.e.*, it is $a\, b \cos \theta$ where θ is the angle between $\mathbf{a}$ and $\mathbf{b}$. Thus what we require is a simple and convenient expression for $a\, b \cos \theta$ in terms of $\mathbf{a}$ and $\mathbf{b}$.

If the vector $\mathbf{b}$ lies along the real axis, *i.e.*, if $\mathbf{b} = b$ we have $\mathbf{a}\,\mathbf{b} = a\, b(\cos \alpha + j \sin \alpha)$.

Now in this case α is the angle between the two vectors, *i.e.*, $\alpha = \theta$, so that $[\mathbf{a}\,\mathbf{b}]_1 = a\, b \cos \theta$, the expression we require, if, following Steinmetz, we denote the real part of a vector, or product of vectors, by square brackets with the suffix $_1$. This is not true unless either $\mathbf{b}$ or $\mathbf{a}$ lie along the real axis.

Now the expression we require only depends on the length of the two vectors, and the angle between them, and not at all on their position with respect to the real axis.

Let $\mathbf{a} = a \operatorname{cis} \alpha$ and $\mathbf{b} = b \operatorname{cis} \beta$. Let us multiply both these vectors by $\operatorname{cis} - \beta$, thus turning them till $\mathbf{b}$ lies along the real axis. If

* *Electrical Review*, February 5, 1904.

we call the vectors so turned $\mathbf{a}'$ and $\mathbf{b}'$, then $\mathbf{a}' = a \text{ cis } \alpha \text{ cis} - \beta$ and $\mathbf{b}' = b$.

Then $\mathbf{a}'\,\mathbf{b}' = a\,b \text{ cis } \alpha \text{ cis} - \beta = a \text{ cis } \alpha\; b \text{ cis} - \beta$, and the real part of this, as shown above, is the expression we want.

Now $b \text{ cis} - \beta$ is the conjugate of $\mathbf{b}$.

Thus $\mathbf{a}'\,\mathbf{b}' = \mathbf{a}\,\bar{\mathbf{b}}$ where $\bar{\mathbf{b}}$ denotes the conjugate of $\mathbf{b}$ and

$$\left[\mathbf{a}'\,\mathbf{b}'\right]_1 = \left[\mathbf{a}\,\bar{\mathbf{b}}\right]_1 = a\left(b \cos(\alpha - \beta)\right) = b\left(a \cos(\beta - \alpha)\right) = \left[\bar{\mathbf{a}}\,\mathbf{b}\right]_1$$

Thus we have arrived at the conclusion that the product of the length of either vector into the projection of the other upon it, is

$$\left[\mathbf{a}\,\bar{\mathbf{b}}\right]_1 = \left[\bar{\mathbf{a}}\,\mathbf{b}\right]_1$$

Similarly it might be proved that

$$\left[\mathbf{a}\,\bar{\mathbf{b}}\right]_j = -\left[\bar{\mathbf{a}}\,\mathbf{b}\right]_j$$

is the "vector part" of the product of $\mathbf{a}$ and $\mathbf{b}$, where the square brackets with the suffix j denote that the imaginary part only of $\mathbf{a}\,\bar{\mathbf{b}}$ is taken. As I shall have no occasion to use this, however, I need not go into it here.

By the introduction of this "scalar part," Mr. Steinmetz's method becomes a system of analytical geometry of great power, as will be found by those who use it.

Let us apply this method to the series motor.

Let $\mathbf{e}_0$ be the impressed E.M.F.
- $\mathbf{i}$ " current.
- $\mathbf{z}_0$ " impedance due to the main flux and iron losses.
- $\mathbf{z}_1$ " impedance due to the resistance and leakage.
- $\mathbf{z}_2$ " armature impedance.

In this motor the following E.M.F.'s occur :—

(1) $\mathbf{e}_0$ the impressed E.M.F.
(2) $\mathbf{e}_1$ the counter E.M.F.
(3) $\mathbf{e}$ the E.M.F. induced in the field by the main flux.
(4) $-\mathbf{i}\,\mathbf{z}_1$ the E.M.F. due to the resistance and leakage of the field.
(5) $-\mathbf{i}\,\mathbf{z}_2$ the E.M.F. due to the impedance of the armature.

Now $\mathbf{e}$ may be expressed in the form $-\mathbf{i}\,\mathbf{z}_0$, and will lag 90° behind the flux, and consequently more than 90° behind the current. Moreover, $e = 2\,\pi\,f\,i\,n^2\,p\,10^{-8}$, where these symbols have the same meanings as in the paper.

Now $\mathbf{e}_1$ lags 90° behind $\mathbf{e}$, and has the magnitude $4\,s\,i\,n\,n_1\,p\,10^{-8}$.

$$\text{Thus } \mathbf{e}_1 = \frac{s}{2\,\pi\,f}\cdot\frac{4\,n_1}{n}\,j\,\mathbf{e}$$

$$\text{Let us put } \frac{4}{2\,\pi}\,\frac{n_1}{n} = a \text{ and } \frac{s}{f} = k.$$

$$\text{Then } \mathbf{e}_1 = -\mathbf{i}\,ajk\,\mathbf{z}_0.$$

Now, by Kirchhoff's law the sum of the above E.M.F.'s must be zero.

$$\therefore\quad \mathbf{e}_0 - \mathbf{i}(\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2) - \mathbf{i}\, a j k\, \mathbf{z}_0 = 0 \quad . \quad . \quad . \quad . \quad (1)$$

the fundamental equation of the series motor. Let us multiply through by $-\overline{\mathbf{i}\,\mathbf{z}_0}$ and take the real part only of the product. We get

$$\left[\overline{\mathbf{i}\,\mathbf{z}_0}\left(\mathbf{i}(\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2) - \mathbf{e}_0\right)\right]_1 = 0$$

(since $\mathbf{i}\,\mathbf{z}_0\,\overline{\mathbf{i}\,\mathbf{z}_0}$ is real, the term involving k is purely imaginary) and k is eliminated.

Multiplying out and dividing by $[\overline{\mathbf{z}_0}(\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2)]_1$

$$i^2 - \left[\overline{\mathbf{i}}\,\mathbf{e}_0 \frac{\overline{\mathbf{z}_0}}{[\mathbf{z}_0(\mathbf{z}_0 + \mathbf{z} + \mathbf{z}_1)]_1}\right]_1 = 0,$$

since $\mathbf{i}\,\overline{\mathbf{i}} = i^2$ a scalar. Writing

$$2\,\mathbf{c} = \mathbf{e}_0 \frac{\overline{\mathbf{z}_0}}{[\overline{\mathbf{z}_0}(\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2)]_1},$$

and factorising again—

$$\left[\overline{\mathbf{i}}(\mathbf{i} - 2\,\mathbf{c})\right]_1 = 0 \text{ or } i^2 = 2\left[\overline{\mathbf{i}}\,\mathbf{c}\right]_1 . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

The first equation asserts that $\mathbf{i} - 2\,\mathbf{c}$ is perpendicular to $\mathbf{i}$, and is therefore the equation of a circle passing through the origin.

Dividing equation (1) by $(\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2)$ and transposing, we get

$$\frac{\mathbf{e}_0}{\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2} - \mathbf{i} = \mathbf{i}\frac{a j k\, \mathbf{z}_0}{\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2}.$$

Setting $\dfrac{\mathbf{e}_0}{\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2} = \mathbf{i}_s$, changing the sign, and dividing by $\mathbf{i}$

$$\frac{\mathbf{i} - \mathbf{i}_s}{\mathbf{i}} = -\frac{a j k\, \mathbf{z}_0}{\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

Now $\mathbf{i}_s$, the standstill current, is equal to OS in Fig. 2, and $\mathbf{i}$ to OI. Thus equation (3) asserts that $\dfrac{\mathrm{SI}}{\mathrm{OI}}$ is proportional to the speed. In fact, the process by which equation (3) was derived from equation (1) suggested the geometrical proof of the circle-diagram, which I gave above. Now Torque × Speed = Output, or

$$\text{Torque} = \frac{\text{Output}}{\text{Speed}}, \text{ or is proportional to } \frac{1}{k}\left[\overline{\mathbf{i}}\,\mathbf{e}_1\right]_1.$$

Thus since $\mathbf{e}_1 = -\mathbf{i}\, a j k\, \mathbf{z}_0$

$$\text{Torque} = i^2 [a j\, \mathbf{z}_0]_1.$$

Now from equation (2)

$$i^2 = [\overline{\mathbf{i}} \cdot 2\,\mathbf{c}]_1 \text{ or } \mathrm{OI}^2 = \mathrm{OM} \cdot \mathrm{ON} \text{ (Fig. 2)},$$

substituting

$$\text{Torque} = [\mathbf{i} \cdot 2\,\mathbf{c}]_1 [a j\, \mathbf{z}_0]_1 \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

Thus the torque is proportional to the projection of the current vector on $2\mathbf{c}$, *i.e.*, on that diameter of the circle which passes through the origin.

The Lines of Constant Output.

Equation (1) may be written

$$\mathbf{e}_0 - \mathbf{i}(\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2) = \mathbf{e}_1.$$

Now Output $= [\bar{\mathbf{i}}\,\mathbf{e}_1]_1$. Let us substitute the value of $\mathbf{e}_1$.
We get

$$\left[\bar{\mathbf{i}}\left(\mathbf{e}_0 - \mathbf{i}(\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2)\right)\right]_1 = [\bar{\mathbf{i}}\,\mathbf{e}_1]_1 = c$$

if we put Output $= c$. This is the equation of a circle, as will be shown below.

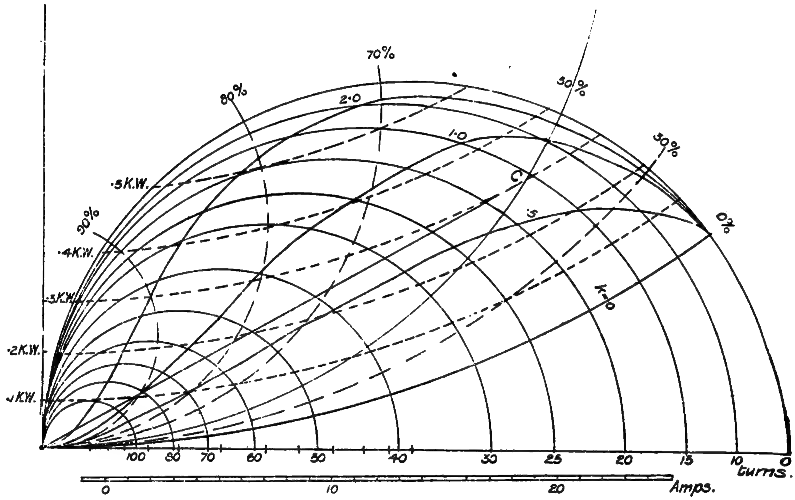


FIG. 15.

Multiplying out, changing the sign, and dividing through by $[\mathbf{z}_0 + \mathbf{z}_1 + \mathbf{z}_2]_1 = r$, the total resistance of the motor, we get

$$i^2 - 2\left[\bar{\mathbf{i}}\,\frac{\mathbf{e}_0}{2r}\right]_1 = -\frac{c}{r}.$$

Adding to both sides $\left|\frac{\mathbf{e}_0}{2r}\right|^2$ we get

$$i^2 - 2\left[\bar{\mathbf{i}}\,\frac{\mathbf{e}_0}{2r}\right]_1 + \left|\frac{\mathbf{e}_0}{2r}\right|^2 = \left|\frac{\mathbf{e}_0}{2r}\right|^2 - \frac{c}{r}.$$

Factorising again, we get

$$\left|\mathbf{i} - \frac{\mathbf{e}_0}{2r}\right|^2 = \frac{e_0^2}{4r^2} - \frac{c}{r} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

The two vertical lines in the above equations form the usual notation for the modulus or absolute magnitude of a complex quantity. The use of an italic letter, though very convenient to denote the magnitude of a single symbol, is obviously inapplicable to a sum of complex quantities such as occurs above.

So long as r, the total resistance of the motor, remains constant, it is obvious that the above equation represents a circle, the vector to the centre being $\frac{\mathbf{e}_0}{2r}$, and the radius $\sqrt{\frac{e_0^2}{4r^2} - \frac{c}{r}}$. Thus when the output is zero the circle passes through the origin. Now it is obvious that the output can only be zero when the speed is zero. Thus we see that the locus of the standstill current vector, as we vary either the field turns or the armature turns, or both, is a circle passing through the origin and having its centre on the line along which the impressed E.M.F. is set out. That the lines of constant output, in practice, are circles, is shown fairly well by Fig. 6, above.

A construction for the radius of the circles of constant output is easily found. Let us describe a semicircle on $\frac{\mathbf{e}_0}{2r}$. If an output circle cuts this at the point c (Fig. 15), then $R^2 = \frac{e_0^2}{4r^2} - \text{o c}^2$.

Hence $\text{o c}^2 = \frac{c}{r}$. This gives us the construction we require.

The Lines of Constant Efficiency.

We have

$$\text{Efficiency} = \frac{\text{Output}}{\text{Input}} = \frac{[\bar{\mathbf{i}}\,\mathbf{e}_1]_1}{[\bar{\mathbf{i}}\,\mathbf{e}_0]_1} = \eta$$

if we put Efficiency $= \eta$, a constant. Substituting for $\mathbf{e}_1$ from the equation—

$$\mathbf{e}_1 = \mathbf{e}_0 - \mathbf{i}\,(z_0 + z_1 + z_2),$$

as was done above, we get

$$\Big[\bar{\mathbf{i}}\Big(\mathbf{e}_0 - \mathbf{i}\,(z_0 + z_1 + z_2)\Big)\Big]_1 = \eta\,[\bar{\mathbf{i}}\,\mathbf{e}_0]_1,$$

or

$$\Big[\bar{\mathbf{i}}\Big(\mathbf{e}_0\,(1 - \eta) - \mathbf{i}\,(z_0 + z_1 + z_2)\Big)\Big]_1 = 0,$$

the equation of a circle passing through the origin.

Multiplying out, dividing by $[z_0 + z_1 + z_2]_1 = r$, the total resistance of the motor, and changing the sign, we get

$$\Big[\bar{\mathbf{i}}\Big(\mathbf{i} - \frac{\mathbf{e}_0\,(1 - \eta)}{r}\Big)\Big]_1 = 0.$$

Thus the diameter of the circle, $\frac{\mathbf{e}_0\,(1 - \eta)}{r}$, gets smaller as the efficiency gets higher. The circle of zero efficiency is identical with the standstill current circle, as one would expect, while the circle of 100 per

cent. efficiency is a mere point (the origin). These circles are shown in Fig. 15. They give us yet another linear construction for the efficiency, though not a very convenient one. Draw a perpendicular from the extremity of any standstill current vector cutting the line of unity power-factor at a certain point P. From the extremity of any other current vector draw a line perpendicular to it cutting the line of unity power-factor in Q. Then PQ measures the efficiency corresponding to that current vector.

Effect of Varying the Number of Field Turns.

In order to consider the effect of varying the number of turns on the field, it is necessary to express the constants of the motor in terms of the number of field and armature turns.

The total reactance of the field is

$$-j\,2\,\pi f\,n^2\,p\,\nu\,10^{-8} = -i\,n^2\,x_0.$$

The total reactance of the armature is

$$-j\,2\,\pi f\,n_1^2\left(\frac{2}{\pi}\right)^2 p_1\,10^{-8} = -j\,n_1^2\,x_2.$$

The counter E.M.F. is equal to

$$4\,i\,s\,n\,n_1\,p\,10^{-8},$$

and differs in phase from the current by a small angle.

Thus it may be represented by $-\mathbf{i}\,k\,n\,n_1\,\mathrm{z}$ where

$$\mathrm{z} = \frac{a\,j\,\mathrm{z}_0}{n\,n_1}.$$

The resistances of the field and armature are proportional to the number of turns on each, if we use the same size wire throughout. The "equivalent resistance" of the field, due to the iron losses, is also proportional to the number of field turns. There will also be a resistance which may be assumed constant, due to the brushes, etc. Thus the resistance of the motor may be expressed in the form $r_0 + n\,r + n_1\,r_1$. However, as the influence of the resistance on the shape of the curves is small, I shall consider the resistance of the motor as a constant, r. The fundamental equation of the series motor now takes the form

$$\mathbf{e}_0 - \mathbf{i}\left(r - j\,(n^2\,x_0 + n_1^2\,x_2) + k\,n\,n_1\,\mathrm{z}\right) = 0 \quad . \quad . \quad . \quad . \quad (6)$$

The first thing that we notice about this equation is that it is of exactly the same form both in n and in n_1. Consequently any curves which we arrive at by considering n_1 as constant and n as variable, will be paralleled by exactly similar curves obtained by considering n as constant and n_1 as variable.

To plot the locus of **i** *in equation* (6) *if* n_1 *and* k *are constant.* Dividing equation (6) by **i**, we get

$$\frac{\mathbf{e}_0}{\mathbf{i}} = r - j\,(n^2 x_0 + n_1{}^2 x_2) + k\,n\,n_1\,z.$$

Thus $\frac{\mathbf{e}_0}{\mathbf{i}}$ or $\frac{1}{\mathbf{i}}$ will move on a parabola, as may easily be seen. The simplest way to plot the locus of **i** seems to be first to plot this parabola, the locus of $\frac{\mathbf{e}_0}{\mathbf{i}}$. The reciprocals of the vectors to this parabola will, to a suitable scale, be the vectors to the curve required.

Now, the reciprocal of a complex number, regarded as a vector, is a vector having a reciprocal length, and making an opposite angle with the real axis to that made by the original vector. We shall evidently obtain the same results if we set out the reciprocals along the line of the original vectors, and then change the direction of rotation of our diagram from clockwise to counter-clockwise, thereby changing an angle α into an angle $-\alpha$, as if we set out the reciprocals, making an opposite angle with the real axis to that made by the original vector. I usually adopt the first procedure as being the most convenient.

Thus with the aid of this parabola it is quite easy to plot the locus of **i** in equation (6) or the curve on which the current vector moves if we keep the speed constant and vary the number of field turns. We obtain a number of points on it corresponding to various values of n. To each of these values corresponds a current circle, such as is discussed above. If we neglect the phase difference between current and counter E.M.F. as has been done for convenience in Fig. 15, these circles will all have their centres on the line of zero power-factor. Since they all pass through the origin, the point just obtained on each serves to determine it completely.

Having obtained, as above, one line of constant speed, and having also the standstill current circle, it is easy to draw as many other lines of constant speed as may be required by means of the speed construction given in Fig. 2.

In Fig. 15 are shown three of these speed-lines. Together with the lines of constant output these lines enable us to determine the torque, output, efficiency, etc., corresponding to any speed and any number of field turns. From the lines of constant speed we see that as we increase the number of field turns, the power-factor rises to a maximum, and then falls slowly down to zero again. In fact, when $n = \infty$ equation (6) becomes

$$\mathbf{i} = \frac{\mathbf{e}_0}{-j n^2 x_0}$$

which has a direction perpendicular to $\mathbf{e}_0$. Thus the speed-lines are all tangent to the line of zero power-factor at the origin. As we saw above, in the paper, the power-factor attains a maximum for a definite ratio of armature turns to field turns, which is independent of the speed. Thus if the number of armature turns be constant, there will be one

current circle in Fig. 15 for which the power-factor will be a maximum at every speed.

In Fig. 11 are given some experimental curves showing the relation between output and number of field turns at constant speed. Although this relation cannot profitably be studied analytically, on account of the complication of the equations involved, Fig. 15 gives us a simple geometrical means of studying it. We see that the point at which the output circle touches a given speed-line, gives us a smaller value of n the greater the speed, till finally, when $k=\infty$ $n=0$.

APPENDIX II.

On the Construction for the Efficiency of the Series Motor.

The construction given in the paper for the efficiency of the series motor is only approximately true,* as may easily be seen by considering the case when $OI=OT$ (Fig. 16). In this case I R is zero, but I H, the perpendicular from I on O S, is not zero. Therefore $\frac{IH}{IR}=\frac{IB}{IA}=\infty$ and the point B must move off to an infinite distance. Thus its locus cannot be a circle, but is a cubic curve, as shown in Fig. 16. However, as the only part of the locus in which we are interested is the part corresponding to points on the current-circle between S and the origin, it is worth while to consider whether this part is not sufficiently near to a circle for all practical purposes. Such a simple construction as the one under consideration should not be abandoned, without full investigation, in favour of constructions which, though exact, are far more complicated. In the first place, it is clear that if it be possible to represent that part of the locus in which we are interested by a circle, this circle may be drawn by the rule given in the paper. The locus obviously passes through S, and, since the point B always lies upon I H (produced if necessary), the locus must be entirely contained between two lines parallel to I H and touching the current circle. Each of these lines will touch the locus at one point. Moreover, by suitably choosing the position of the point C (Fig. 16), the point B corresponding to any position of I may be made to lie anywhere on the line I H. Thus *any* circle through S, touching a line drawn parallel to I H, and tangent to the current circle near the origin, will do.

A complete investigation, by the aid of the calculus of variations, into the difference between the actual locus and a circle described in this manner, would be far too complicated to be given here. However it appears to be possible to show briefly that in all practical cases the curve does not differ much from a circle.

In one case the curve actually is a circle, viz., when O S coincides with O T. In this case the point B coincides with the point A, and its

* I am indebted to Mr. L. M. Rampal for pointing this out.

locus is therefore a circle of centre C, and radius equal to that of the current circle. Thus we see that the nearer O S approaches to O T, *i.e.*, the greater the angle of lag of the standstill current, the nearer is the curve to a circle. Consequently, if we can show that when the angle

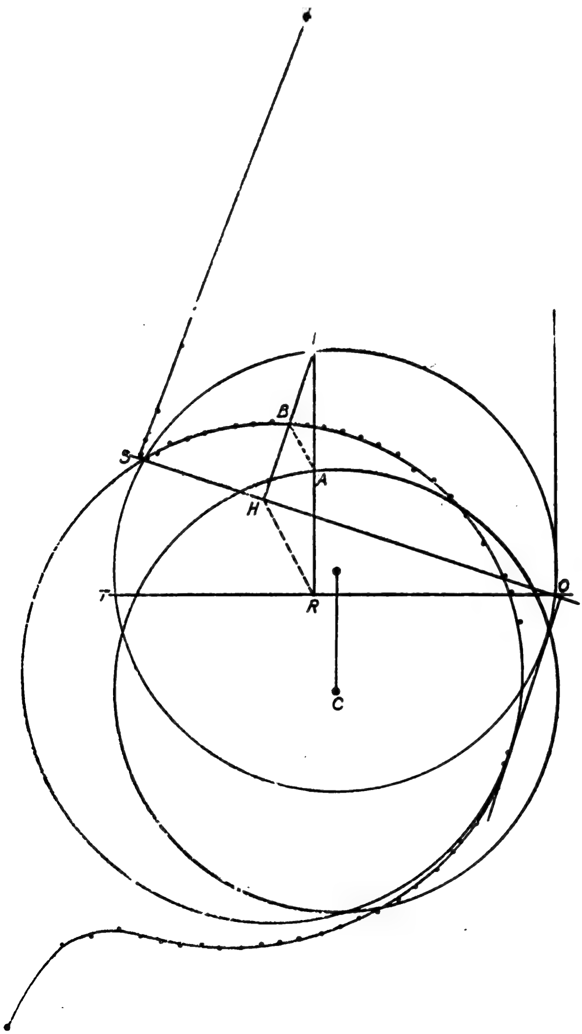


FIG. 16.

of lag of the standstill current is small, say not more than 45° (and a motor having such losses would never be tolerated in practice), the curve is nearly a circle, it will follow that in all practical cases it may be represented by a circle. Any one sufficiently interested may show

for himself that, in such a case, the difference between the locus and a circle is barely perceptible. In Fig. 17 I have drawn out such a case as

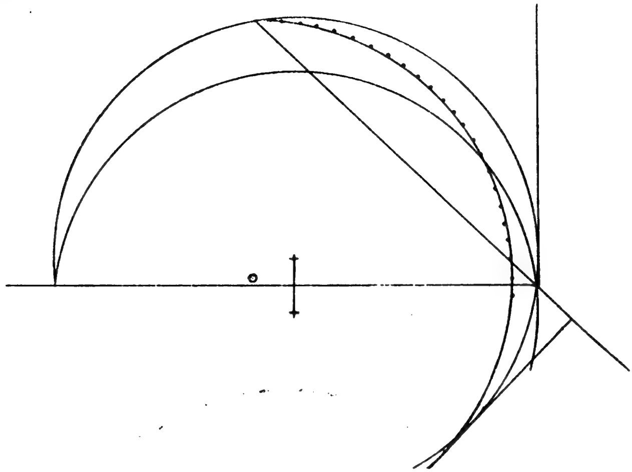


FIG. 17.

carefully as I could. It may be seen that the circle represents the locus of the points exceedingly well.

APPENDIX III.

FURTHER EXPERIMENTS ON THE SERIES MOTOR.

The following appendix contains an account of some further investigations on the series motor. Since the investigations described above had rendered the method of designing an alternating-current series motor fairly clear, it was decided to endeavour to re-design the experimental motor, so as, if possible, to make it into a practical machine. The working out of the design from the constants of the carcase p, p_1, and ν, which had been measured before, is given as an example above. However, as it had been decided to make a pair of slots in the pole-faces, and to put a compensating coil therein, this was rather a leap in the dark, as of course the slots and compensating coil entirely alter the constants of the carcase, and no means were at hand to estimate the effect they would produce. However, it was thought that if the motor was designed so as to be as good as possible with the unmodified carcase, it could not but be better when fitted with the compensating coil. A scale drawing of the shape of the stampings is shown in Fig. 18.

When the motor returned after these alterations had been made, the first thing done was to ascertain the effect of the slots on the constants

of the carcase, first, before the compensating coil was put in, and, second, after it was in place. The following results were obtained as the mean of a number of observations of the impedance of the armature :—

$$\text{Before the making of the slots} \left(\frac{2}{\pi}\right)^2 p_1 = 60 \text{ nearly.}$$

$$\text{After} \quad ,, \quad ,, \quad ,, \quad ,, \quad \left(\frac{2}{\pi}\right)^2 p_1 = 48 \text{ nearly.}$$

$$\text{After the compensating coil was put in} \left(\frac{2}{\pi}\right)^2 p_1 = 31{\cdot}5 \text{ nearly.}$$

Thus the effect of the slots and the compensating coil was practically to halve the impedance of the armature.

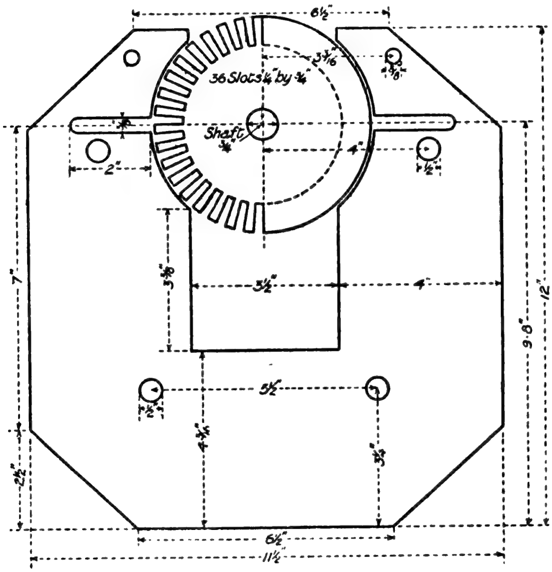


FIG. 18.—Diameter of Bore, 5⅜ in. Diameter of Armature, 5¼ in. Depth of Stampings parallel to Shaft, 3½ in.

The compensating coil consisted of a single turn of 19/14 cable passed through both slots, and the ends sweated up. As a result of making these slots, however, the leakage coefficient was slightly increased. The reason of this, of course, is that the slot increases the reluctance of the main magnetic circuit as compared with the leakage magnetic circuit. With a suitable design of the carcase, *i.e.*, a design in which the iron is disposed symmetrically round the armature so that none of the main flux need pass across the narrow neck at the back of the slot, this need not occur. Such designs of field magnet are the Ironclad type or the ordinary multipolar type. By comparing the counter E.M.F. of the motor with the E.M.F. induced in the field

coils, and also by means of direct experiments, it was found that the leakage coefficient, although it varied somewhat, averaged about 1·3. On account of the flux being alternating, its measurement was a very easy matter. A search coil containing 52 turns of fine wire was made, and solidly taped round. This made an extremely flexible coil of round section (¼ in. diameter), which could be placed anywhere on the machine. If it be desired to measure the flux through a given area, it is only necessary to place this coil round the area; and the ratio of the E.M.F. induced in it, to the E.M.F. in another coil of 52 turns wound directly over the exciting coil, will be the ratio of the flux through the given area, to the total flux. By means of this coil it was found that, as the mean of a number of observations, about 0·36 of the total flux passes through the part of the pole-face above the slot, and 0·41 through the part below. It was also found that by giving the brushes a lead in the direction of rotation, the leakage coefficient could be reduced slightly. With the aid of this flexible search coil, some leakage tests were taken during the progress of a brake test, the machine running under normal working conditions. It was found that the leakage coefficient did not vary much with the load, but remained constant at about 1·3. A considerable number of brake tests were next made in the endeavour to ascertain the efficiency, and also the effect on it of varying the number of field turns, of using different sizes of brush, etc., a D.C. shunt motor being used throughout as brake. It must be understood that the figures for the efficiency, given below, were not made to include the friction and windage of the series motor, since these present no features of special interest.

As a result of these experiments, it was found that the efficiency was distinctly low. In the hope of raising it, experiments were tried with an increased number of field turns. It was found that above about 2,000 R.P.M. the efficiency became practically constant at about 65 per cent. whatever the number of the field turns, the nature of the brushes, etc., though occasionally higher values were obtained, never exceeding 70 per cent.

The fact that increasing the number of field turns beyond a certain limit produces very little effect on the efficiency is very well illustrated by Fig. 19, which contains a number of curves in which the efficiency at various speeds is plotted against the number of field turns. These curves are derived from the same series of experiments on which Figs. 6, 10, and 11 are based. They show clearly that the efficiency at first rises quickly with the number of field turns, but soon ceases to do so, only increasing very slowly with increasing field turns. Before leaving these experiments it ought to be mentioned that the efficiency curve corresponding to 54 turns in Fig. 10 is almost certainly a good deal too high. During the test the output was so small that most of it was consumed by the friction of the two machines, and consequently a small error in determining this produced a large error in the efficiency. Fig. 15, the complete circle-diagram, also shows us the same thing as Fig. 19. As we increase the number of field turns, keeping the speed constant, the current vector will travel along one of the lines of

constant speed. Now it can be seen from the diagram that for large values of n, the number of field turns, the efficiency lines and the lines of constant speed are nearly parallel. Consequently, to obtain a given increment of efficiency, we must move a considerable distance along the speed-line. Now when n is large, a given increment of n only produces a small change in the position of the current vector, as the diagram shows. Thus, to obtain a given increment of efficiency, we shall have to make a very large increase in the number of field turns, or, in other words, the efficiency only rises very slowly with increasing field turns.

At the commencement of the experiments the motor was fitted with

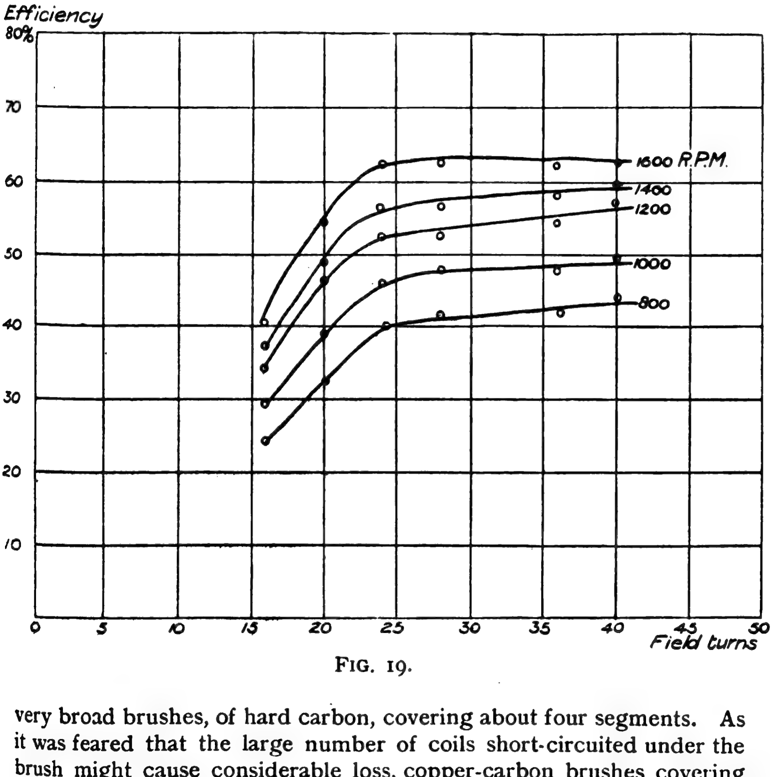


FIG. 19.

very broad brushes, of hard carbon, covering about four segments. As it was feared that the large number of coils short-circuited under the brush might cause considerable loss, copper-carbon brushes covering three segments, and narrow brushes of very soft carbon covering one segment, were tried in succession. Neither of these produced any material effect on the efficiency, but perfect commutation was obtained with all three types of brush. It seemed as if the narrower the brush the softer the carbon allowable.

Thus, from these experiments, it appeared that the efficiency could not be raised much above 65 per cent. by any modifications of field turns, brush resistance, etc. The next step appeared to be to ascertain

the cause of this low efficiency. In order to do this an analysis of the losses occurring during a brake test was made in the three cases corresponding to 52, 84, and 104 turns.* This analysis was carried out in the following manner: Taking advantage of the fact that the same current flows through both field and armature, it is possible to read either the total input of the motor, or the watts given to the armature, direct on the wattmeter, according as the P.D. coil is placed across the whole machine, or across the armature only. The difference between these readings will be the field losses, which may thus be measured under actual running conditions during the progress of the test. The field losses could, of course, be measured by placing the wattmeter direct across the field, but as this involves taking readings at a very low power-factor the above method is to be preferred. The field

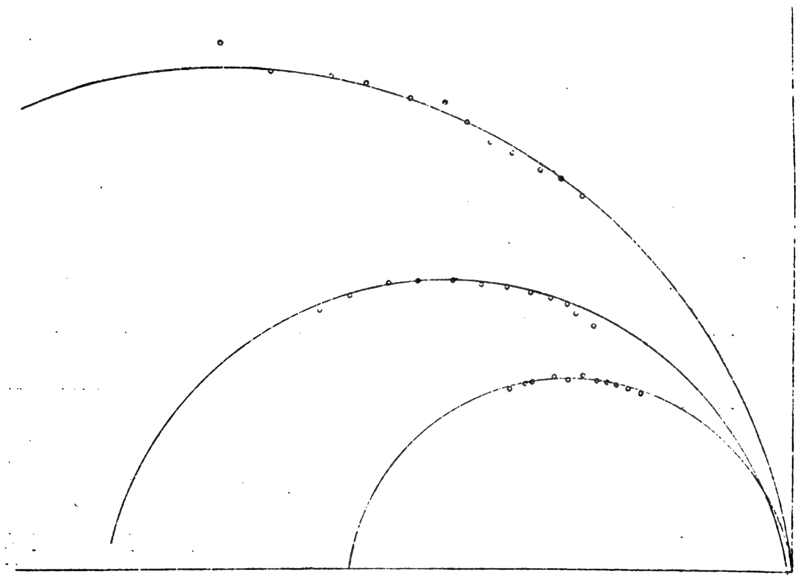


FIG. 20.

losses include the I^2R loss in the field, the hysteresis and eddy loss due to the alternation of the flux, and the losses in the coils short-circuited under the brush. The I^2R loss in the armature, the loss in the compensating coil, and any other stray armature losses, were measured in the following manner: Arrangements were made, by means of a two-way double-pole switch, for switching on either alternating or direct currents, of equal magnitudes, to the armature. The power consumed by each of these was measured on the wattmeter, and the difference taken as the loss in the compensating coil. The power consumed by the direct current is, of course, the I^2R loss only. By reading this

* These analyses were all made at 25 frequency.

on the wattmeter, we eliminate any error in the ammeter, or in determining the resistance. By switching on the field of the series motor while being driven by a D.C. machine, and noting the increase in the input of the driving machine, the iron losses due to rotation were measured. Lastly, by lifting the brushes and again observing the loss in the field when the current is switched on, we may separate out the loss in the coils short-circuited under the brush. The results of these three tests are shown in Figs. 20, 21, 22, 23, and 24.

In Fig. 21, Curve I. represents output plotted against speed (here the

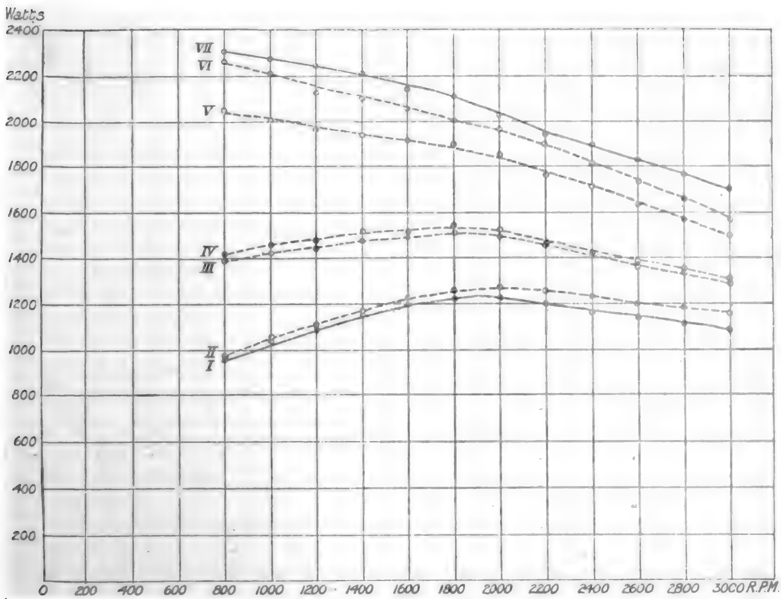


FIG. 21.—52 Turns on Field.

output includes friction losses). In Curve II. the iron losses due to rotation have been added.

In Curve III. the field losses proper have been added also.

Curve IV. includes the losses in the coil short-circuited under the brush.

Curve V. includes the I^2R losses in the armature.

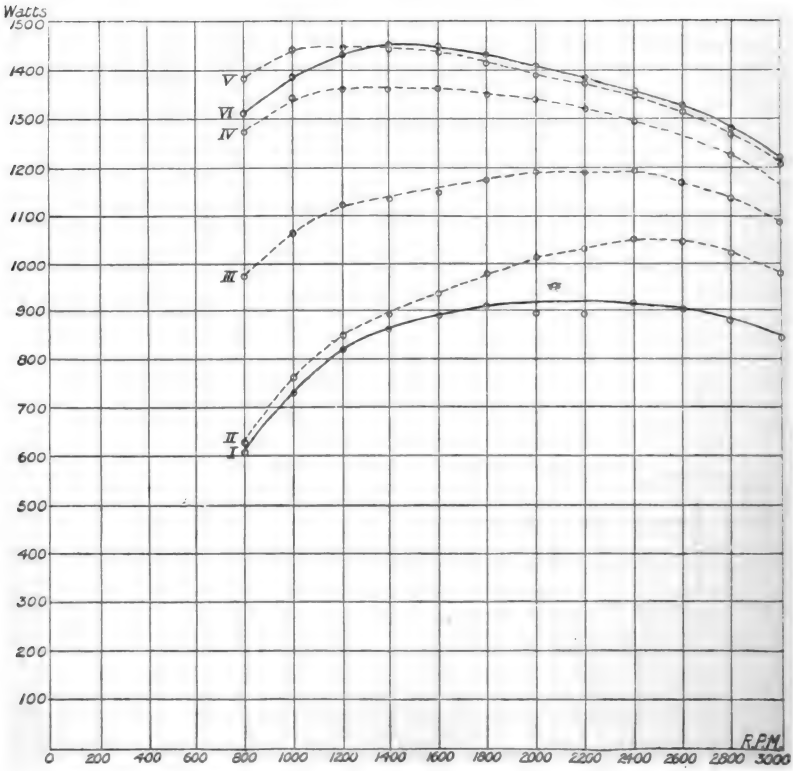
Curve VI. includes the compensating coil losses.

Curve VII. represents the input.

In Figs. 22 and 23 the losses are added to the output in the same order, except that Curve III. represents the field losses *including* those in the coils short-circuited under the brush. Thus the curves are numbered differently, there being only six curves instead of seven.

In Fig. 22 it may be seen that the I^2R loss in the armature is the greatest (the motor being perhaps overloaded). This amounts at the

working speed (2,000 R.P.M.) to about 15·5 per cent. The field losses are nearly as great, being 11·2 per cent. The losses in the compensating coil are 5·1 per cent., and the iron losses due to rotation 1·8 per cent. The losses in the coils short-circuited under the brush are quite insignificant. If we now turn to Fig. 23, giving the analysis of losses when we have 104 turns on the field, we see that the field losses are by far the largest, forming 17·9 per cent. of the input. The copper losses only form 7·1 per cent., the compensating coil losses 3 per cent., and the iron



ɔ 1. FIG. 22.—84 Turns on Field.

.ɔ the alt

under the rotation 6·1 per cent. Fig. 22, giving the analysis of losses pensating co 84 turns, forms an intermediate case. A comparison of the following ures is very instructive. It shows that the principal way double-poıfficiency becomes constant at so low a value as 65 per currents, of equ be raised by increasing the number of field turns, is by each of these iron losses. These are probably largely due to taken as the loss hine has flat cast-iron end-plates bolted direct on by the direct current field coils enclosing both stampings and end- feature I was unable to alter. Fig. 21 in

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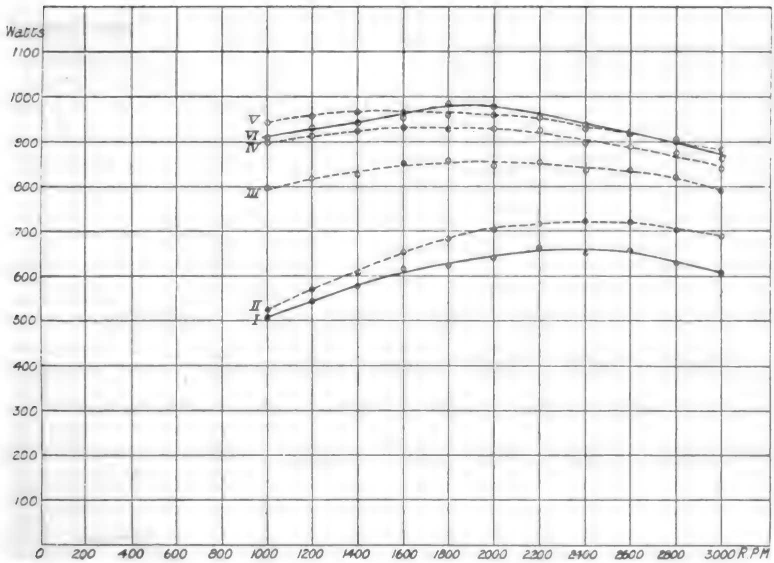


FIG. 23.—104 Turns on Field.

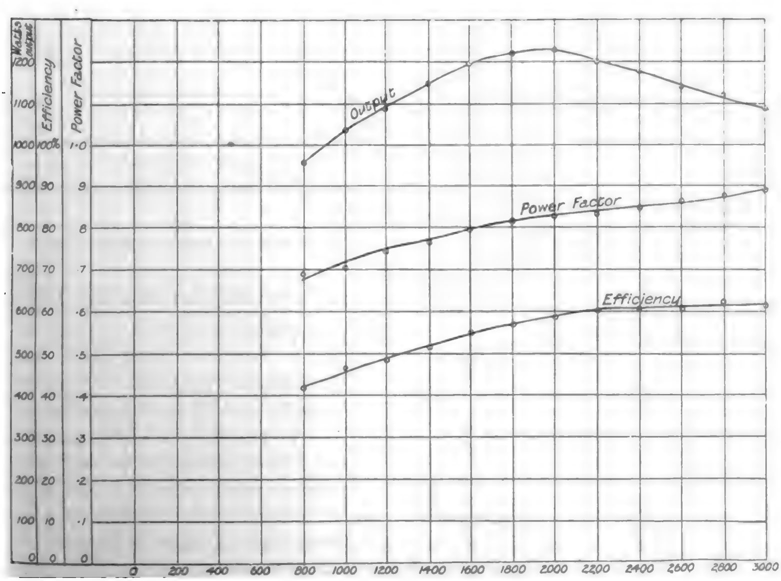


FIG. 24.

particular, shows that the resistance of the machine is far too high. The resistance of the armature over the brushes is in fact 0·43 ohm. The other losses are not, I think, excessive, except perhaps the hysteresis due to rotation, which, in Fig. 22 especially, seems very high. In connection with this, it seems rather remarkable that in Fig. 21, when there were only 52 turns on the field, and consequently the flux was stronger than in the other two cases, the hysteresis, etc., due to rotation, is the smallest. It will also be noticed that the output + losses is considerably less than the input, and this suggests that the hysteresis due to rotation has been underestimated. In Fig. 20 are given the three circles corresponding to the tests in Figs. 21, 22, and 23. It should be mentioned, in this connection, that, since the compensating coil was put in, the centres of many of the circles observed have lain below the line of zero power-factor. A possible explanation of this seems to be the following: Unless the plane of the compensating coil is exactly perpendicular to the brush-line (and this can only occur for one particular brush-position) an E.M.F. will be produced by the rotation of the armature in the flux due to the compensating coil. This E.M.F. changes its direction as we move the brushes past the position of perpendicularity to the plane of the compensating coil. If it is in phase, instead of opposite in phase, to the current in the latter, it will tend to reduce the angle θ (Fig. 2) and may even make it negative, thus depressing the centre of the circle below the line of zero power-factor.

In Fig. 24 are shown curves of output, power-factor, and efficiency, plotted against speed. These were taken at 90 volts, 25 frequency, and with 52 turns on the field. They represent on the whole about the best performance of which the motor under test is capable. The output is excellent if we consider that the motor is about the size of an ordinary 1-H.P. direct-current machine. It weighs, in running condition, 169 lbs.

At 100 volts the output would, of course, have been greater, certainly not less than 2 H.P. at 2,000 R.P.M. It was, however, found impossible to keep the voltage of the generator up to 100 with the heavy currents taken. The power-factor, too, is very fair, but the efficiency is decidedly low.

At 2,000 R.P.M. we have—Output = 1,230 watts; power-factor = 0·83; efficiency = 59 per cent.

If we compare this with the specification given above, we see that, allowing for the effect of the compensating coil, they agree very fairly. The output is very much greater, as one would expect, since it is proportional to the square of the current passing through the motor, the power-factor is better, which is also what one would expect, and the efficiency is lower, which is accounted for by the compensating coil losses and the iron losses due to rotation, which were not taken into account in the calculations. Thus we may be fairly sure that a motor designed by the methods described above will fulfil its specification.

The faults of the motor experimented on, and their remedy, are rendered quite clear by the above analyses of losses.

It is clear that in order to obtain a higher efficiency, a higher

counter E.M.F., that is, more turns on the armature, are needed. In order to decrease the armature $I^2 R$ losses, a larger gauge wire is required. Thus the armature must be made considerably larger than in present direct-current practice. On account of the very small space occupied by the field winding a much more compact design of field magnet is possible, thus decreasing both the weight, the reluctance, and the iron losses. The iron, as mentioned above, should be

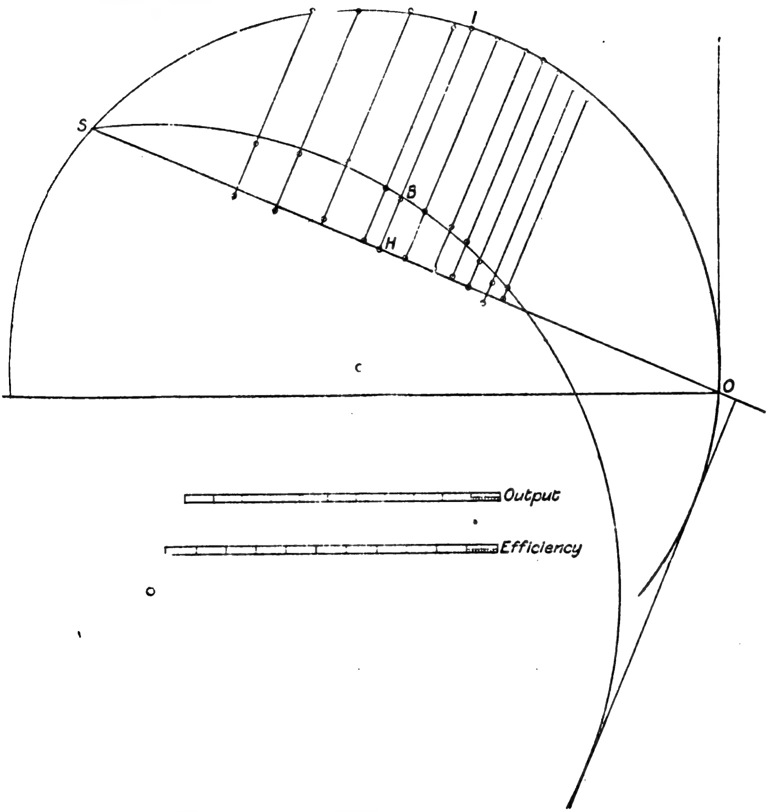


FIG. 25.—Experimental Verification of the Output and Efficiency Constructions.

distributed symmetrically about the axis of the main magnetic flux. A motor built in this manner would have good efficiency and high power-factor, while the output per lb. would probably be even higher than in the motor tested, which at full load gave 9 watts per lb., 100 volts being applied. The reason why such good "weight efficiencies" are obtained with so small a motor is on account of the large number of armature turns employed. Though this method of design is adopted for quite other reasons, it is precisely the one recommended by Mr.

Hobart in his book "Electric Motors," and elsewhere, as giving good "weight efficiency" in direct-current motors. In fact, when this experimental motor was tested with direct current, it gave about 3 H.P. at 1,400 R.P.M., with an efficiency of about 70 per cent., 100 volts being applied. The low efficiency is explained by the high I^2R losses, as we have seen above. In this case we got 12·5 watts per lb., very nearly.

It has been shown experimentally above, that in the alternating-current series motor the current moves on a circle as we vary the speed, and that the speed may be found by the construction given in Fig. 2. It is also clear that the torque is proportional to the square of the current. These two constructions being assumed, the constructions for output, efficiency, etc., follow mathematically, no further reference to the series motor being necessary. It was thought of interest, however, though not strictly necessary, to attempt a direct experimental verification of the two latter constructions, more especially as a verification of the efficiency construction would enable us to test whether the theoretical result that the efficiency is 100 per cent. at infinite speed, supplies us with a satisfactory efficiency scale. Fig. 25 gives us an experimental verification of the output and efficiency constructions given in Fig. 2.

A perpendicular I H was dropped from a point I on the current circle on to the standstill current, its length measured, the output corresponding to this point noted, and from these two observations the scale to which I H represents the output was found. Setting off the outputs corresponding to the other points on the current circle along lines through these points and perpendicular to O S, we get a series of points which, as Fig. 25 shows, lie very closely along O S, thereby verifying the output construction. The efficiency circle was next drawn, according to the rule given above, the length of I B and the (observed) efficiency corresponding to the point I noted, and from these the efficiency scale determined. Setting out the efficiencies corresponding to the other points on the current circle, from these points, in the same way as the outputs, a series of points is obtained, which, as may be seen, lie very closely along the efficiency circle. This verifies the efficiency construction. Comparing the efficiency scale as determined experimentally above with that deduced from the assumption that the efficiency is 100 per cent. at infinite speed, it was found, as had been suspected, that they did not agree, the latter scale giving efficiencies which were a good deal too high. Thus in practice it will be necessary to determine the efficiency scale experimentally.

Thus it will probably prove impossible to obtain a satisfactory test on the series motor by means of one or two observations taken at standstill, as may be done in the case of the induction motor. A brake test will always be necessary. It may be pointed out here that the Hopkinson test is perfectly applicable to the series motor, the power required by such a motor being supplied by another, exactly similar, coupled to it and acting as a brake. The wattless current taken by the machine, however, cannot be so supplied, and thus the generator must

supply both the losses and the wattless currents required by both machines.

Throughout the series of experiments described above, it has been found impossible to obtain satisfactory experimental values of the standstill current, on account of the fact that the contact resistance of the brushes is much higher at standstill than when running. This effect will probably occur in all commutator motors, though it may be less marked in large machines. It produces a slight decrease of the current and a considerable increase in its power-factor on account of the enormous commutator losses. It was frequently found that the power-factor of the motor when running at a slow speed, say 80 R.P.M., was *lower* than that at standstill, on account of the above effect. It was found impossible to keep the motor stationary for long with current flowing through it, as the brushes rapidly got red-hot.

I have usually been obliged to deduce the standstill current from the observations of current, etc., when the motor was running, by means of the speed construction. In verifying the speed construction itself, the following method was adopted: According to theory, as may easily be seen, if O S (Fig. 2) does not correspond to zero speed, but to some other speed, say a R.P.M., then S P will be proportional, not to the actual speed s, but to $s - a$. Thus, if we plot S P against the measured speed, we ought to obtain a straight line, whatever the position of O S. This was found to be the case, and this fact forms the real verification of the speed construction. For one, and only one, position of O S, the curve between S P and the measured speed was found to pass through the origin. This was taken as the correct position, and is used in the curves given in Fig. 7 above.

In conclusion, my thanks are due to Messrs. Nightingale, Chaffer, Nealor, Hodgkinson, King, and Herbert, for their assistance in the experiments described in this appendix. I have also to thank Mr. Nightingale for his assistance in preparing some of the figures.

Joint Discussion of B. J. Arnold's Address on the Alternate-Current Motor applied to Traction,* and of F. Creedy's Paper on the "Alternating-Current Series Motor."

(*April* 27, 1905.)

Mr. T. H. Schoepf: At the foot of page 50, item 1 reads as follows: "Raising the speed, if allowable." The speed of an alternating-current motor of the series or repulsion type is naturally higher than that of a direct-current series motor of equal capacity, the principal limitation being the peripheral speed of the commutator. It is not practicable to exceed a certain maximum speed without providing an excessively large commutator to furnish sufficient mechanical strength to resist the displacement caused by the enormous centrifugal forces developed. In order that a single-phase motor may have a good characteristic and commutate well, the armature ampere-turns must be relatively great compared with the field ampere-turns, which means that there must be many turns on the armature for an equal number of segments in the Mr. Schoepf.

* See vol. 34, p. 229.

Mr. Schoepf. commutator. In traction work the size of the motor is influenced by the available space within the bogie truck, and as this space is necessarily small, the diameter of the commutator must be kept as small as possible, in order to allow sufficient space for properly-designed brush-holder gear, and for this reason the armature speed must be kept as low as possible in order to use single reduction gears. Therefore I say that it is commercially impossible to design a series alternating-current motor for traction work, and get a better power-factor by increasing the armature speeds.

The second item at the top of page 51 reads as follows: "Lowering the frequency. It will, as a rule, be much easier to design a satisfactory series motor for low frequencies than for high, though I believe it can be done for any frequency not much exceeding 50." In making this statement Mr. Creedy, no doubt, refers particularly to motors for industrial purposes, such as cranes, machine drive, etc., rather than to motors for traction work, and I think if he should attempt to design a motor for traction work—we will say one of 100 or 150 H.P. capacity, such as I have had the opportunity of testing within the past few weeks—he would meet with many difficulties that are not easily overcome. I think that for the present a maximum frequency of single-phase motors for traction work will be 25 periods, but in some instances, with small capacity motors, the manufacturers may design and build motors of higher frequency. I myself believe that in the near future we shall see single-phase motors of higher frequency than those in commercial operation, but I do not think that we will see them over 50 periods, and I believe it will be a long time before we will see them, of large capacities, operating at above 25 periods. The difficulties to be met in designing a motor of this type for high frequencies are quite apparent. The principal difficulty to overcome is the natural tendency to spark, and the commutation may be improved by suitably designing the winding.

The third item referred to reads as follows: " By suitably designing the winding." In designing a motor of this type one always bears in mind that it must have high efficiency as well as a high power factor. These two features are influenced by a third, which is, perhaps, of not such great importance as the two first mentioned, but is one that must always receive careful consideration, and that is the shape of the speed curve. With the rate of change in speed, with a given change in amperes, the motor may have a sharp characteristic, or it may have a more gradually changing characteristic; and for the different classes of work you must take into consideration the shape of the curve, and you must get a curve which will give the best results generally, unless, of course, you have an opportunity to design motors specially for the work in hand.

The *Electrical Times* contained a criticism on this paper, and I noticed an error in the reference to the Westinghouse motor to which I should like to call attention. This criticism contains three diagrams, and describes the Westinghouse motor as having a short-circuited neutralising winding. This is not correct. The single-phase, alter-

nating-current series motors as designed by Mr. Lamme have a neutralising winding in series with the armature, and when the armature is reversed the neutralising winding is also reversed. For further information on this subject I refer to discussions before meetings of **Mr. Schoepf**

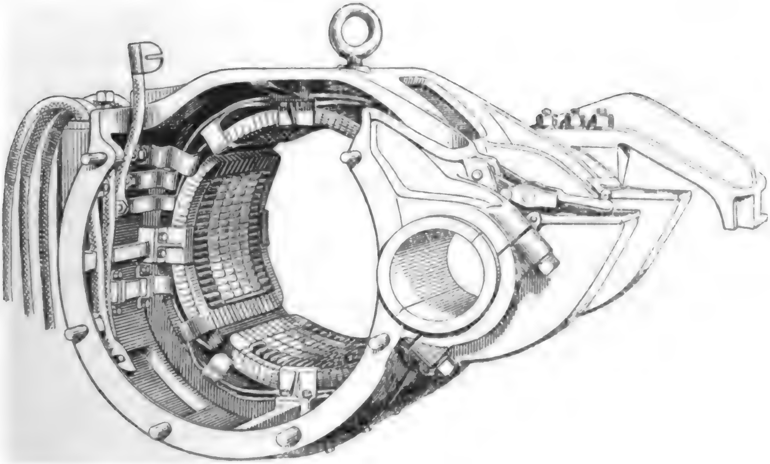


FIG. A.

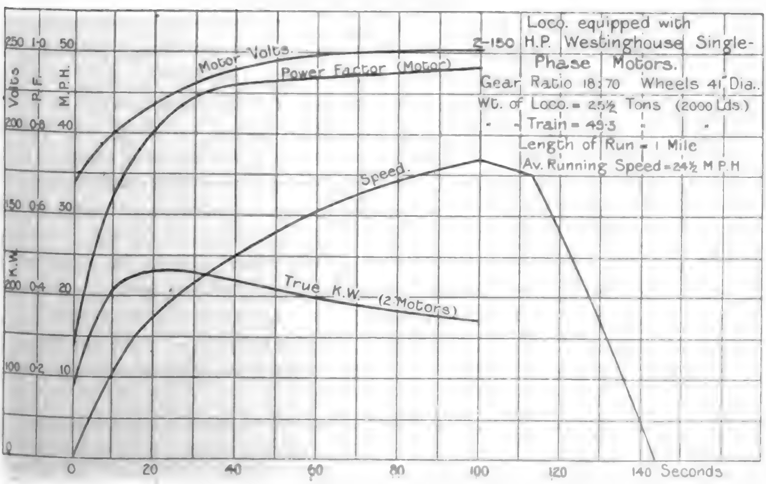


FIG. B.

the American Institute of Electrical Engineers in New York and Pittsburg during January and February, 1904. Fig. A is a photograph showing the neutralising winding of this motor.

Mr. Schoepf. Fig. B shows the actual results obtained from a test which I made on a locomotive equipped with two 150 H.P. motors. The locomotive was one which was sold to a customer, and I went to Pittsburg especially to conduct the test before shipment, and the curves are the results of this test. I may say that the gear ratio is rather high, meaning in this case the actual ratio, which is 70 to 18, as the locomotive is not intended for high speed work, but is intended more for freight.

You will note that the speed curve bends over slowly after what is commonly termed the accelerating period, rather than bending over sharply and attaining top speed quickly, as one would expect from a locomotive designed for high speed passenger service, or a train having several motor coaches where the ratio of gearing is low. Referring to the power-factor curve, it will be seen that the power factor at start is approximately 26 per cent., and it bends over sharply at the end of the accelerating period, and attains a maximum of approximately 96 per cent. With reference to the power-factor curve, I wish to call attention to the fact that the voltage applied to the motors during the tests was controlled by an induction regulator, which, of course, has an inductive component of its own, and will naturally make a slight reduction in the power factor of the entire system.

It will be noticed that the kilowatt curve is quite flat during the accelerating period, which gives rather a peculiar appearance, but this was the result which was intended, as it is desired to keep the demand on the station as low as possible. The class of service under consideration influences one's decision as to whether constant amperes or constant true kilowatts shall be maintained during the accelerating period. With locomotives for long-distance runs with only occasional accelerating periods, one does not wish to instal a power-house of large capacity, and therefore one makes every effort to maintain constant true kilowatts rather than constant amperes; whereas on suburban systems designed for frequent accelerating periods and high speed working one will make every effort to maintain constant amperes, as this determines the heating of the motors, and the average demand upon the power-house is not greatly influenced by the resulting peak in the kilowatt curve for the motors.

I have also produced here a curve showing the volts on the motors, the starting voltage being approximately 165. For the various equipments the induction regulator is actually adjusted for the voltage required. The rate of acceleration is approximately one mile per hour per second with a train weighing about 66 tons, and starting on a straight and level track.

While at Pittsburg I saw in the process of manufacture a motor of 225 H.P. capacity, and went very carefully over the calculations for this motor. The actual results obtained with motors of 50, 75, 100, and 150 H.P. capacity compared very closely with the calculated performance, and this indicates that the 225 H.P. motor will prove equally satisfactory in service. This motor was designed to operate on 18 periods, but will operate equally well at a little higher voltage on 25 periods, the power factor and efficiency being somewhat lower.

Mr. A. RUSSELL: I was much interested in Mr. Creedy's paper, and more particularly in his circle diagram illustrating the working of the alternating-current series motor. This diagram is more general than the one ordinarily given, as the iron losses are taken into account by means of an angle θ. It is stated that this angle is constant, but no hint is given as to why it is constant, and so this point has to be considered. If we make the assumption that the number of commutator segments is infinitely large, it is not difficult to see what the angle θ really is. The E.M.F. generated by the rotation of the armature is in exact opposition in phase to the flux, and thus the angle θ is the phase difference between the flux and the exciting current of the field magnets. In a series motor the maximum values of the flux are very different for different loads on the motor. The hysteresis loops for these different maximum values differ in shape, and so we are not at liberty to assume that the phase difference between the flux and the magnetising current is constant, although possibly it may not vary much over the working range of the motor. Even, however, if it were constant it is doubtful if we could take it into account graphically in a diagram showing the currents and electromotive forces for different working conditions, as, when there is iron present, the wave shapes of the currents and electromotive forces are not only different, but vary with the maximum value of the induction. For instance, suppose that the flux follows the sine law, then the magnetising current is shaped like the tooth of a carpenter's saw with the point rounded off and has a pronounced third harmonic. If the maximum value of the induction density in the loop be 4,000, the amplitude of the third harmonic is about 20 per cent. that of the first harmonic. We cannot assume, therefore, that all the vectors can be represented by lines in a plane. It is better, I think, to make our assumptions boldly at the start, and then compare them with the results of experiments. We shall assume, therefore, straight away that the permeability of the iron is constant. This is a very large assumption to make. If we consider the hysteresis loop, it is easy to see that the ratio of the magnetic induction to the magnetic force, so far from being constant actually varies from plus infinity to minus infinity during the cycle. It is an assumption, therefore, that must not be lightly made. It can be shown, however, that in certain cases it is permissible. Making this assumption, we get a diagram which is very easily proved and very instructive. Mr. Russell.

If, following Mr. Creedy, we assume that the line joining the brushes is perpendicular to the line joining the middle points of the pole faces, and that the number of commutator segments is infinite, there will be no transformer action, as the mutual inductance between the field magnet coils and the circuits joining the brushes will be zero. The E.M.F. generated by the rotation may obviously be written in the form $M \omega i$, where M is a constant, ω the angular velocity of the armature, and i the instantaneous value of the main current which, on our assumptions, would be in phase with the flux. In practice, the current and the flux are not in phase, and this produces a lag θ as in Mr.

Mr. Russell. Creedy's diagram. In the simplified problem the equation to find the current is

$$e - M\omega i = Ri + L\frac{di}{dt},$$

or

$$e = (R + M\omega)\,i + L\frac{di}{dt},$$

where e is the instantaneous value of the applied P.D. and R and L are the resistance and inductance of the motor circuit. This equation is identical in form with that for an ordinary inductive coil. It can thus be represented graphically as in Fig. C.

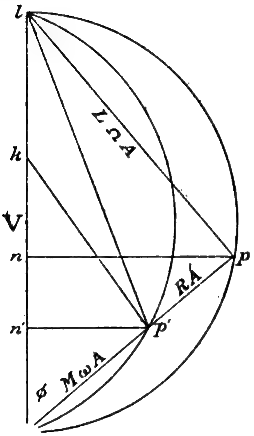


Fig. C.

This diagram was first given by Professor Blondel. In the figure Ol is the effective value V of the P.D. applied at the terminals of the motor. The line lp, when the applied wave is sine-shaped, represents L Ω A, where $\Omega/2\pi$ is the frequency of the supply, and A is the effective value of i. Op represents $(R + M\omega)$ A, and the angle lOp is ϕ, where $\cos\phi$ is the power factor. Make $pp' = $ R A, then the angle $lp'p$ is constant, since its tangent is always equal to $L\,\Omega/R$. The angle O$p'l$ is, therefore, also constant, and thus the locus of p' is an arc of a circle. As ω increases the power factor $\cos\phi$ continually increases and the current $lp/L\,\Omega$ continually diminishes. We have :—

$$\text{The input} = V\,A\cos\phi = A.Op = R\,A^2 + M\omega A^2.$$

The useful power is, therefore, $M\omega A^2$, and the average value of the torque is M A^2.

We also have :—

$$pn \doteq Op\sin\phi = Op \times L\,\Omega\,A/V = \text{input} \times L\,\Omega/V,$$

$$\text{and } p'n' = Qp'\sin\phi = M\omega A^2 \times L\,\Omega/V = \text{output} \times L\,\Omega/V.$$

If, in the figure, we draw $p'k$ at right angles to Op, we have—

$$\eta = \frac{\text{output}}{\text{input}} = \frac{p'n'}{pn} = \frac{Ok}{Ol}.$$

If the effective value of the P.D. applied to the motor be constant we see that Ok will be proportional to the efficiency. If Ol be 100, Ok will be the percentage efficiency. The above construction still applies when the applied wave of P.D. does not follow the harmonic law. In this case the value of Ω depends on the shape of the applied wave of P.D. Its minimum value is $2\pi f$, where f is the frequency, and it has this value when the waves are sine-shaped.[1] The complete

[1] Russell, *Alternating Currents*, vol. 1, p. 80.

problem, when the brush line is not perpendicular to the line joining the middle points of the pole-faces, has been fully worked out by Professor André Blondel. See "Notes sur les moteurs monophasés à collecteurs," *L'Eclairage Electrique,* November 28, 1903. He proves that the above diagram still holds good in this case, but the values of M and L depend on the angle the brush line makes with the line joining the middle points of the pole faces. If we neglect armature reaction, M is a maximum when this angle is a right angle. The torque also, due to a given current, is a maximum in this position. If we move the brushes from this position in the direction of rotation, L is increased, and, if in the opposite direction, L is diminished. Mr. Russell.

It is not easy to understand why the effect described in the following sentence was produced. "It was also found that by giving the brushes a lead in the direction of rotation the leakage coefficient could be reduced slightly." I presume that by "leakage coefficient," Mr. Creedy means the "ν" defined earlier in the paper. It is better, I think, to call this coefficient "Hopkinson's coefficient," and to reserve "leakage coefficient," or, better, "leakage factor" for the coefficient "σ" ($= 1 - M^2/L_1L_2$) which comes in when we take the transformer action into account, as we need to do in the theory of compensated series motors. There are many other points in this interesting paper which one might profitably discuss. For instance, the Figs. 21, 22, and 23—more particularly Fig. 22—show that the iron losses due to the rotation of the armature are far from being negligible. This shows that those compensated-series motors, the Latour motor for instance, in which when they are running near synchronous speed ($\omega = \Omega$) a rotating magnetic field is produced, will, for this reason alone, have a higher efficiency than the simple-series motor. The paper shows clearly that the simple alternating-current series motor is not as efficient as the direct-current series motor.

Mr. L. CALISCH: Having had some experience with single-phase traction, I would like to make a few remarks on the subject of electric traction by means of single-phase motors. At present there are two distinct types of single-phase motors which compare favourably with the D.C. series motor with regard to starting torque and speed characteristics, namely:— Mr. Calisch.

(1) The series motor. (2) The repulsion motor and its numerous modifications. Mr. Creedy has given us an excellent theoretical investigation of the series motor, and has cleared up a number of doubtful points; there still remain, however, a good many practical points to be discussed. He has carried out a considerable number of experiments with the straight-series and compensated-series motor. For practical railroad and tramway work, the straight-series motor has long ago been abolished, and for this class of work only the compensated motor needs to be considered, as the straight-series motor has too low a power factor, on account of the high impedance of armature and field, and commutation is far from good. The object of putting on a compensating coil is to diminish the self-induction of the armature, which increases the efficiency and improves the power

Mr. Calisch. factor and commutation. There are two ways of compensating—(1) the compensating coil may be in series with the armature and main current, (2) the compensated coil may be short-circuited, and act as the short-circuited coil of a transformer. Both methods are equally good, The General Electric Company uses the first—(the motors on the Schenectady—Ballston line were compensated this way), the Westinghouse uses the second. The proper method of making the pole-pieces does not seem to be settled. Mr. Creedy, on page 51 of his paper, recommends salient pole-pieces like a D.C. motor. The Westinghouse Company used this method of field construction, but the General Electric Company uses a laminated iron field with slots, just like an induction motor field with distributed winding. M. Latour in France, and M. Osnos in Austria, both recommend an induction motor field with a distributed winding in preference to salient pole-pieces. If it can be shown that salient pole-pieces are better (which I doubt), and the field can be made like a D.C. motor, then this would be of enormous practical value, as it is very hard to replace a coil in an induction motor field when a coil burns out, while it is comparatively easy to do so in a D.C. motor. At present it is impossible to make an A.C.-series motor for above 250 volts, which is a disadvantage, as is also its high running speed. On the other hand, such a motor runs either A.C. or D.C., a great advantage, and its starting torque and speed characteristic is nearly as good as that of a D.C. motor. The repulsion motor, which also has a series characteristic, is essentially a transformer, there being no connection between armature and the field. This motor can be built for high voltages, and, therefore does not necessitate a transformer on the car. The acceleration is excellent, a little better than that of a series motor; its power factor at starting is, however, low, and therefore takes a large wattless current at starting. Repulsion motors can also be compensated, and a great number of combinations can be made. Time does not permit me to enter into them. A series-repulsion motor is, however, in use, namely, the Winter-Eichberg motor, with which excellent results have been obtained in Germany. Repulsion motors have been built for 2,000 and 3,000 volts. After a great many years of experimenting, the General Electric Company adopted the compensated-series motor for serious railroad work, notwithstanding they were holding Elihu Thomson's original repulsion motor patents. Perhaps it may be interesting to give a few details of the motors and equipment of the General Electric Company as used on the line between Schenectady and Ballston, in the State of New York, and which some of you have seen. There are four compensated-series motors on the car, each of 50 H.P. The motor consists of an induction motor field with distributed winding. The motors are wound for 200 volts each, and two are permanently connected in series. The field winding is in two sections, which are in series for D.C. running and in parallel for A.C. running, as this proportion of field-winding gives better results. Parallel-series control is used with rheostats. The car is operated at a trolley voltage of 2,300 and 25 F cycles, which is stepped down by means

of an air-cooled 80 k.w. transformer to 400–440 volts. The interurban section is operated by means of the A.C. current, the city section by means of 500 volts direct. The car weighs, completely equipped with motors, etc., 30·4 tons, and attains on the level a speed of about 45 miles per hour. The following figures may be of interest:—Efficiency, including gear losses, etc., A.C. 70–79 per cent., D.C. 75–85 per cent., power factor 0·95. Mr. Calisch

Professor C. A. Carus-Wilson: The alternating-current series motor is one of those things we all want to know more about. I am glad to have had the opportunity of listening to two gentlemen who have had these machines under their care and who are actually acquainted with their manufacture. Unfortunately, owing to a certain amount of trade rivalry, we have not heard many details about these motors; in fact it has been difficult to get any definite information. We know that they can run sparklessly, thanks to the use of the compensating coil and to the method of putting motors in series by which the voltage of each motor is reduced. But we want to know what is the practical result of putting the motors in series. The last speaker seemed to express the opinion that it was a serious disadvantage, due to the tendency to slip, which, of course, we are all acquainted with in direct-current coupled motors in series; one motor slips, and the whole load is thrown on to the other motor. Then in connection with the question of power factor, we have seen diagrams of certain alternating-current motors running with certain stated power factors, but we are no wiser for this information. An alternating-current series motor can be designed for any power factor you like; it simply depends on the air-gap. We want to know what amount of air-gap these alternating-current series motors are being run at which give these power factors; and if either of the gentlemen who have spoken are able to state what gaps were being used in those motors to which they referred, I think it would be of general interest. This question of the power factor is dealt with at length in Mr. Creedy's paper. I do not allude to the point he takes up about the efficiency, because he simply deals with the electrical efficiency, neglecting all the core losses in the motor. But with regard to the power factor, what we want to know is whether the design which has to be adopted in an alternating-current series motor to get a high power factor is a design well adapted for railway work—that is to say, in an alternating-current series motor we are working under the disadvantage of having to face the difficulty of the power factor. This can be got over, but in doing so and in getting a high power factor, are we led into a design which is prejudicial to good work on a railway? That is the practical thing we want to know. I cannot help thinking that this question of power factor can be looked at in rather a simpler way than that put forward by Mr. Creedy, though, of course, his is quite a correct way of putting it. It is much simpler to look at this question from the point of view of the back volts in the motor. The peculiarity of the A.C. series motor is that the back volts do not consist simply of that due to the motion of the armature as in the D.C. motor, but also of back volts due to frequency in the field. Professor Carus-Wilson.

Professor Carus-Wilson.

These two are at right angles to one another. For instance, if you have the same number of turns on the field and armature, and supposing there was no leakage, then at the speed of synchronism the two back volts would be equal, and we should have a power factor of 0·7. The power factor simply depends upon the ratio of the back volts in the armature due to the motion to the back volts in the field due to the frequency. Obviously in order to get a high power factor we must increase this ratio. In his paper Mr. Creedy discusses some of the ways in which this can be done, but he has overlooked one very important fact. In designing a motor the designer has to keep constantly before him the limitations due to rating. You cannot take a motor as Mr. Creedy does and say, "We will ring the changes on the windings until we get the best results, *i.e.*, the highest power factor." You have to consider what is going to be the effect on the current rating, and your choice is limited by this. Consequently these experiments that Mr. Creedy has made, although interesting, are unpractical, because they do not take account of the limitations imposed by the rating. In the case of an ordinary direct-current motor, if the winding on the armature is altered, you have to alter the current rating. For instance, if the armature-turns are increased, the current rating must be decreased nearly in the same proportion. Now how does this apply to the A.C.-series motor? If the armature-turns are decreased, we can have a larger current in the motor, and do with fewer turns on the field. Fewer turns on the field with the same flux means a diminished back volt due to self-induction in the field, while at the same time fewer turns on the armature means a higher speed and higher back volts due to motion, so that by reducing the number of turns on the armature, subject always to the limitations of rating, you get a better power factor. The question, then, is whether this result of few armature-turns agrees with the accepted results of good design for a railway motor. It does, because, as every one knows, the tendency of good design is to reduce the number of turns on the armature, because thereby for the same amount of temperature rating you get a very large increase of H.P. output; so that in this respect the principles of good design in A.C. and D.C. series railway motors agree. But there is an important difference. One of the great advantages of fewer turns on the armature in a D.C. motor is that at the full-rated speed the core losses are less than the C^2R losses. The result of this is that when the motor is starting, and the core losses are very small, a very large increase of current can be permitted during the period in which the motor is speeding up, that is, the starting current may be far larger than the current allowed at the rated speed. This is the explanation of the enormous overloads that we find in such motors as those on the Liverpool Overhead Railway, where 200, and even 300 per cent. overload during the moment of starting is allowed. But the case is entirely different with the A.C. series motor, because even at rest you have the hysteresis losses due to frequency, and it is impossible in these motors to draw such large overload currents because you are not able to work above the bend of the magnetisation curve. So that as far as I can see it will be

impossible to draw anything like the overload currents at starting with the A.C.-series motor that you can with the D.C.-series motor. If this is so, it would seem that the field of usefulness of these motors is in high-speed long-distance running, where few stops are required. Professor Carus-Wilson.

Professor W. E. AYRTON: Mr. Russell, in the interesting remarks he made, pointed out a very probable error in the circle diagram which Mr. Creedy has worked out and described in the early pages of his paper, the apparent error being that he has assumed all the quantities to be sine functions of the time, not merely the applied potential difference, but every other varying quantity; and Mr. Russell suggests that, as motors do really contain iron, perhaps it is somewhat rash to assume that this circle diagram would apply to an actual single-phase alternating-current series motor, and that experiments ought to be made. But is not that exactly the essence of Mr. Creedy's paper? He has started by describing how, making very simple measurements—*i.e.*, measuring with a voltmeter the applied P.D., with an ammeter the current, or a fraction of the current, say at full load, and the stand-still current when the motor is not running, using a wattmeter to measure the power in each case so as to get the power factor in each case—he has shown how, having carried out those definite measurements, you can draw a circle, and how with that circle, for the given applied P.D. and the given frequency, you can at once obtain the input, the output, the efficiency, and the power factor when the armature is running at any speed you like. The experiment has only to be made at two speeds, the speed corresponding with full load and the stand-still speed. Professor Ayrton.

Next Mr. Creedy has gone on to construct such a series motor, and carry out a series of experiments with it, and show that the points obtained by experiment do really lie on such circles as described on pages 56 and 59 of his paper. So I venture to think that what Mr. Creedy has really done is practically what Mr. Russell advocated should be carried out; that is to say, the development of an easy method of obtaining these various quantities graphically on the assumption that there is no iron—*i.e.*, that everything follows the sine law—and then making the experiments and seeing whether the graphical method really holds and enables you easily to determine from it the various quantities.

I do not think, however, Mr. Creedy has quite done himself justice—that is to say, he has not with sufficient clearness explained this. He has not sufficiently, I think, brought out in this paper what he has actually accomplished; he has, in fact, made the mistake, which so very often young people commit, of assuming that everybody must know at least as much as they know. If a man has been working at a particular subject for a considerable time, even although he may have a considerable amount of youth, he may know a great deal more than other people a good deal older than himself on that particular subject. Therefore I would put in a word of caution in connection with one or two parts of his paper. For instance, in the last paragraph but one on page 47 he says: "Since we have output = I H, and obviously

Professor Ayrton.

input = I R, we have efficiency $= \frac{\text{I H}}{\text{I R}}$." I am not suggesting that Mr. Creedy does not understand what he means when he writes that. I am only suggesting that less able people may fall into error, because, as a matter of fact, the output does not equal the line, nor is it, in a sense, even proportional to the line, because if you say the output is proportional to I H, then you must remember that the input is proportional to I R on a very different scale. If you refer to Fig. 2, and look at I H and I R, you will see that I H is about 18 millimeters long and I R 30 millimeters long, and therefore you might assume that the efficiency for the particular speed referred to in the figure was 64 per cent. But that is not what is meant. You have really to find out first what is the scale of I H and what is the scale of I R, which are totally different, before you can get the efficiency from the relative lengths of I H and I R.

On page 49 a very interesting result is arrived at theoretically. It is one of the results which I understand Mr. Creedy has not tried experimentally, and I would strongly advise his doing so. It is perfectly well known that with an ordinary direct-current motor the greatest output is obtained, *i.e.*, it works with the greatest activity when it is running with 50 per cent. efficiency. With a series alternating-current motor, on the contrary, he has proved theoretically that when you get the greatest output you may have considerably more than 50 per cent. efficiency. I suggest to him that it would be a very important point to try that experimentally.

Nobody who has spoken up to the present time has referred to the very interesting series of diagrams, etc., in connection with commutation. They bring out, as Mr. Creedy himself states, the great importance of the oscillograph over any of the other methods of endeavouring to delineate a varying current or a varying P.D. Mr. Mather and myself felt years ago that the oscillograph, an instrument which writes out at once the instantaneous values, and gives you the complete curve, not the mean of a number of curves, would be far better than anything of the Joubert point-by-point method. Therefore it was not until we more or less failed to develop the oscillograph into a commercial form that we tried the other instruments, some of which were described at the British Association at Ipswich in 1895, of which the most perfect at this time is the ondograph, that very pretty instrument shown by Professor Hospitalier at this Institution in 1903. All those instruments give you the wave in a very simple form, but they give you not a single wave, but the average. They act exactly like the ordinary steam-engine indicator, which gives you a curve, the indicator diagram, and gives it you really as the mean value of a number of waves. If you imagine an engine running 100 or 150 revolutions per second, of course you will see at once what you would get. You would get your curve, but obviously it would be a mean curve, and if you are dealing with changes in the conditions, as you are in this commutation, then any such instrument as the ondograph would be hopeless for that purpose. The ondograph works perfectly well

at 100 periods, even provided that the wave is somewhat irregularly shaped, if it be repeated exactly over and over again, but for such effects as are depicted in the pages of this paper such an instrument, as Mr. Creedy points out, is useless. As I say, we felt that; and although we described, and Messrs. Barr and Rodgers, two of our students, also described, different methods at the same meeting of the British Association, we felt that the oscillograph was the thing really to come back to; and, thanks to Mr. Duddell, it was the thing which was come back to with enormous success. Professor Ayrton.

There is another important result which is arrived at by Mr. Creedy at the end of his paper, and that is that the armature, of this particular motor at any rate, should be relatively the important part, and the field magnet the less important. In other words, he comes to the conclusion at the bottom of page 42 that what he ought to do to get success is to exaggerate the armature field and to diminish that of the field magnet. Many of you know that is the thing that Professor Perry and I have been advocating for many years—some twenty-five years—that in a motor, if you want practical efficiency and weight efficiency, and also in this case power factor, although that does not concern direct-current motors, what you should employ is a relatively important armature and a relatively less important field. Why that was laughed at and why it was not used I think is probably due to the fact that twenty odd years ago the difficulty of sparking was a very serious one. We had not the carbon brush, and we had not the other methods of destroying sparking now well understood; but now we have these methods I venture to suggest that a re-reading of the 1883 paper that we offered to the Society at that time might be worth even Mr. Mordey's consideration. (Mr. Mordey: "No!") Of course, Mr. Mordey is obdurate. Mr. Creedy, from his experiments, has come to that result in the case of his particular motor. I was extremely interested to hear the experience of my former student, Mr. Calisch, since he left me, and since he has been in America working at these single-phase alternating-current motors; and I hope that Mr. Creedy, who has only just now left me, will get the same measure of success. At any rate, I think you will agree with me that he has started well in giving the Institution, as a mere student, this paper.

Mr. W. M. MORDEY: Like Professor Ayrton, I should prefer to hear the experience of those who have done actual work on one-phase alternate-current motors. For my part, I have talked about that subject and written about it, but unfortunately I have not done any work on it. Mr. Mordey.

We must congratulate Mr. Creedy on his paper, which is particularly interesting and significant as the work of a student. I have, however, not mastered it sufficiently to say anything useful on it, but I would like to refer to the other subject down for discussion to-night—the address given in America to the joint meeting of the two Institutions by the President of the American Institution, Mr. Bion Arnold. I am sure we all sympathised with Mr. Arnold in the misfortune he suffered some two years ago, when his experimental one-phase loco-

Mr. Mordey. motive was destroyed by fire the night before it was to be tried on a railway. The arrangement was very ingenious and interesting, but I hardly think Mr. Arnold would have put it forward or have worked it if he had had what we have to-day, the knowledge of the progress that has been made in the development of laminated one-phase commutator motors. You may remember that he proposed to use a one-phase induction motor, driving the train through a curious variable ratio gear consisting of a compressed engine and a compressed air-motor. That arrangement is well worth study.

In his address Mr. Arnold questions whether electrical engineers are going to have it all their own way in electrifying main-line railways. There is a passage on page 230 of the *Journal* (vol. 34) which may be quoted :—

> "Those who have given the subject little thought, or who are unable to analyse it carefully on account of the lack of technical knowledge necessary to appreciate the difficulties to be overcome, are most apt to predict the early supremacy of the electrically-driven train over the locomotive."

That is a very necessary warning. That Mr. Arnold is not a pessimist is, however, to be seen from another passage in his address (page 234) with which most of us will agree. He says : "With the single-phase motor and the steam turbine a reality, with the transmission problem almost solved, and with the rapid development of the internal combustion engine now taking place, are we, as engineers, not warranted in believing that we can so combine them into a system which will ultimately supplant the steam locomotive motor in trunk-line passenger and freight service?" We here would answer yes to this question, although probably none of us go so far as to believe that we shall ever see the end of the steam locomotive. That, or some other heat motor, is bound to stay in all cases where it will not pay to equip a railway electrically.

If I am not out of order, I would like to refer to another statement—one made by our Past President, Colonel Crompton, in his James Forrest address the other night before the Institution of Civil Engineers, where he said—if I did not misunderstand him—that the steam locomotive was capable of development to enable it to do everything that an electrical train could do. He was speaking to Civil Engineers, and perhaps he wished to be a very civil engineer himself ; but I would ask whether there are not some things the electric locomotive or the electric-driven train can do to-day that the steam locomotive cannot do to-day, and, so far as we can see, can never possibly do ? Is there a steam train to-day which, in spite of all the years of work spent on locomotives, can accelerate at much over 1·3 ft. per second, which is one-third of the rate attained on the Liverpool Overhead Electric Railway ? Is there a steam-driven train that can go up a 10, 12, or even a 14 per cent. grade ? That is an important question, because on the answer to it may in some cases depend the amount of grading that must be done at very great cost. In any case, electric trains can climb grades that are far beyond

the scope of the steam locomotives. We must remember that the electrical train is something like a caterpillar in its hold on the ground. By putting motors on every axle, or on many axles, advantages in adhesion are got that cannot be got by any practical conceivable arrangement of steam trains. Another quality is that of regeneration. When the steam locomotive can use the energy, now spent in braking, to heat the water in its own boiler, it may perhaps claim to partly imitate the electrical qualities of regenerative control. Is it likely that any reciprocating steam locomotive will ever be able to run at the magnificent speeds made by the electric locomotive on the Berlin-Zossen line? If reciprocations restrict speed, it is, of course, possible that the steam turbine locomotive may get over that, but even the steam turbine cannot pick up its energy as it goes along. Non-stop runs need only be limited by the length of the railway with electrical driving. Mr. Mordey.

There are other points, but I have mentioned sufficient to show that we ought not to let Colonel Crompton encourage the Civil Engineers to think we are not going to drive their trains electrically. I believe on all busy lines we shall soon see a great deal of electrical driving, and that it will be largely by one-phase methods, but I do not think any of us will live to see the steam locomotive entirely displaced by the electric train.

With reference to one-phase railway motors in practice, as I have seen several of them and have had the opportunity of testing them, I am able to say that, so far as sparking is concerned, there is nothing to choose between them and direct-current traction motors. In all practical requirements, judging from tests in the shop and experiments on actual lines, they can do everything that direct-current motors can do, although with some loss of efficiency of the motors themselves.

The efficiency of a series-laminated commutator motor must necessarily be lower than that of a direct-current motor. The loss is very nearly twice as much; that is to say, if a direct-current motor has an efficiency of 90, an alternate-current motor will have an efficiency of not much over 80 per cent.; but the efficiency of the train itself will be higher, as well as that of the whole system, whether for long or short lines. There are gains in various directions which far more than compensate for the extra loss in the motors.

There is one interesting detail in the Westinghouse one-phase motor to which I may refer—the introduction between each sector of the commutator and the armature of a very high resistance connection. It is an old device. Many of us have used it or tried it in direct-current motors. In these alternate-current motors it is supposed to improve the collection. Whether it does so or not I do not know, but the collection is certainly very good. I refer to it to draw attention to an effect I have never seen mentioned, though I have often thought of it in connection with commutator leads and commutator heating. Has it been realised that in this part of the circuit a frequency of many hundreds, or even of some thousands per second, exists? Take the case of an ordinary armature run at 1,000 revolutions

Mr. Mordey. per minute in a twofold field, and having 120 commutator sectors, then in each lead and commutator sector as it passes the brush the current will reach the brush with an impulse at the rate of 120,000 per minute, or 2,000 per second, that is equivalent to 1,000 periods per second (the ordinary idea of frequency, however, scarcely applies, as there is only an impulse in one direction). With more poles or a higher speed the periodicity will be proportionately higher.

It should be noted that this higher frequency is not sensibly higher in alternate-current commutator motors than in direct-current machines. In either case the skin effect—the Kelvin effect—may be so considerable as to increase very perceptibly the effective resistance of the part of the circuit in which commutation is taking place.

Professor Smith. Professor R. H. SMITH: I should like to interpolate one remark with regard to what Mr. Mordey has just said as to Colonel Crompton's James Forrest lecture. The context of his lecture shows that he only referred to long-distance runs upon railways, and on those long-distance runs acceleration is of very little consequence indeed.

Mr. Punga. Mr. F. PUNGA (*communicated*): I think that these tests will prove very useful in the development of the alternating-current series motor; nevertheless, there are quite a number of points which require comment. On page 48 the author states that the series motor is much superior to some other single-phase motors in which, as the circle diagram shows, it is very difficult to get good power factor concurrently with good efficiency. The way in which the author has made this comparison is certainly unfair. To attempt to judge whether the curves of efficiency and power factor have their maxima at the same output by looking at the circle diagram and noting the shapes of the curves representing these quantities, will lead to erroneous conclusions. The only right way to compare these types of motors involves the laborious preparation of a set of designs for a line of series motors and a line of propulsion motors, and from the results of these designs alone is it safe to draw conclusions as to the relative merits of these two types? That the efficiency results and the author's method of obtaining them cannot be very accurate, may be gathered from the fact that he uses as a comparison the efficiency at infinite speed, and takes his efficiency to be 100 per cent. It is, however, a fact that the output at infinite speed is nought, since the constant losses bring the efficiency to nought.* Even if the author should explain that his efficiency is a different efficiency, of what use is his definition if it changes 0 per cent. to 100 per cent.? A comparison between the repulsion motor and the series motor shows that neither as regards efficiency nor power factor is there any very striking difference; the only important feature that has quite a different aspect in these two types of motors is the commutation and the influence of the commutating coils, and it is to be regretted that so very little has been said about commutation in this paper. The ways in which commutation may affect the design of the series motors have not been considered at all by the author. There is no doubt that the greater part of the conclusions which the author

* In fact, it is less than nought, it is negative.

Mr. Punga.

draws from his pretty circle diagram would have to be modified were considerations of the commutation not overlooked. The reason why the series motor has for so long a time been considered to be impracticable will be found in the fact that questions relating to its commutation were not understood.

I should like at this point to give briefly the results of an exhaustive study of the commutation of the prominent types of single-phase motors. I define as "sparking voltage" the geometrical sum of the "reactance voltage" and the induced voltage, and I can prove that this voltage is the main factor responsible for the sparking in commutating machinery, for direct-current as well as for alternating-current. This "sparking voltage" has also a physical meaning. Thus, if we observe the distribution of the current under the brushes, we find that the current is not uniformly distributed under the brushes. For instance, Fig. D gives us the typical distribution of the current under the brushes of direct-current generators. If we take brushes with uniform specific resistance, the voltages that can be measured between brush and segment would be proportional to the current densities, and would, therefore, have at one end of the brush the value A B, at the other end

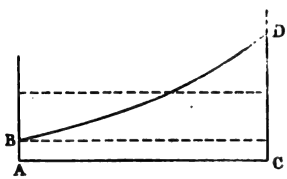


FIG. D.

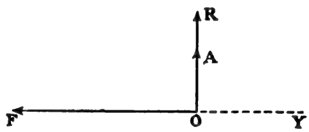


FIG. E.

the value C D, the difference C D — A B being the "sparking voltage" per brush, and $\frac{\text{C D} - \text{A B}}{\text{No. of segments covered by brush}}$ is the "sparking voltage" per segment. For the different types of single-phase motors the "sparking voltage" can be found as follows: In Fig. E, let O Y be

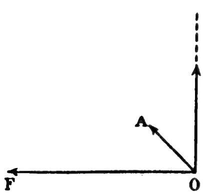


FIG. F.

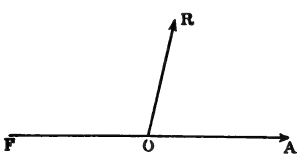


FIG. G.

the direction of the current of an alternating-current series motor, then O R is the reactance voltage, and O A is the voltage induced by the rotation of the commutating coil in the flux produced by the armature ampere-turns ("rotation voltage"). O F is the voltage induced by the fluctuation of the flux emanating from the poles ("fluctuation voltage").

Mr. Punga. The geometrical sum of these three vectors is the "sparking voltage" per segment. Fig. F shows the same diagram for a series motor with compensation of armature inductance. The only factor that has changed is the vector O A ("rotation voltage"). O A has become considerably smaller, and now lags behind the current. Fig. G shows the same diagram for a repulsion motor as well as for the short-circuited brushes of a compensated repulsion motor. The striking difference is the direction of O A, which is now directly opposite to O F. At synchronism we have approximately

O F = O A, and
"Sparking voltage" = "Reactance voltage."

Under these conditions the commutation is very nearly the best. At a speed equal to double synchronous speed O A = 4 O F, and the "sparking voltage," which is equal to the geometrical sum of O R and (O A − O F = 3 O F), will generally be from three to four times as great as at synchronous speed. At half the synchronous speed O A = ¼ O F, therefore O F − O A = ¾ O F. As O F is comparatively large at half-synchronous speed, the total sparking voltage will also be large. From these considerations it can be clearly seen that there is a striking difference in the commutation of repulsion motors and series motors. In the first type there is at synchronism very good commutation, as the reactance voltage is generally considerably smaller than the "fluctuation voltage," or the "rotation voltage," at higher speeds as well as at lower speeds, the commutation becomes very bad. For the series motor there is not such a striking favourable speed as for the repulsion motor, but the commutation does not become impaired with variations from synchronous speed so quickly as for the repulsion motor. It would lead too far to indicate even roughly the influence of these facts on the design of such motors; it would be necessary to go into the most important of all factors, *commutation at starting*, and to show the connection between starting torque, current rush at starting, and commutation at starting. Of very nearly the same importance as the commutation is the influence of the commutating coils on the field—a fact which has already been mentioned by Steinmetz, and which can also be deducted from Mr. Creedy's experiments. From Fig. 1 we see that the axis of the armature ampere-turns does not go through the middle of the brush, but would go further to the right. This very simple explanation leads to a series of surprising results. On measuring the short-circuit current of a direct-current machine, with the brushes in the neutral zone, it will be found that that current depends upon the peripheral thickness of the brushes employed, but not in the way that a thinner brush corresponds to a smaller short-circuit current (as one would expect), but in many cases, especially with copper brushes, in the opposite direction. The influence of the commutating ampere-turns is the reason for this.

I have found a general formula for this influence, namely: A T per pole $= \frac{1}{12}$. Turns per segment × (Segments covered by brush)²

$\frac{\text{"Sparking voltage"}}{\text{Resistance of brush per set}}$. Now this amount had an exceptionally great value in the experimental motor described in the present paper, and as the above formula gives only an average value, the instantaneous value varying as much as 8 per cent. from the average value in the case of four segments covered by a brush, there must be an influence on the field which varies whenever a segment enters under the brush. The total variation at its maximum may be very roughly calculated as some 15 per cent. of the field ampere-turns. An exact calculation, unfortunately, was not possible, as the author has not given all the dimensions of his motor—an omission which I hope he will make good in his reply to the discussion. All the ripples which can be seen in the E.M.F. curves are due to that effect, and the best proof that there also exists for direct current, such a phenomenon, though in a lesser degree, is the experiment made by the author of sending direct current through his motor and testing the constancy of the flux. Mr. Punga.

I should like to point out a few further defects in the paper. The angle O, which the author on page 46 attributes to the iron losses, and which he estimates as being very small in amount, seems to be a very erratic factor, judging from Fig. 5. The centre of the circles should lie on one side of that angle, the other side being the X axis. Fig. 5 contains a few points with a power factor beyond unity. This the author explains by the large C^2R losses in the field—an explanation which is not very satisfactory. In Fig. 8 the starting current should be inversely proportional to the frequency, according to the author's own theory. How, then, are we to reconcile the curve for 25 periods having a smaller ratio than the above law, with the curve for 18 periods having a considerably larger radius? Why should the angle θ be negative as soon as compensation is employed? Here I would also further observe that since a motor without compensation has, at the present time, considerably less practical interest than one with compensation, the principal tests made by the author would have been of greater use, and his theory of greater interest, had he applied his calculations and his analytical deductions to a motor having a compensated coil, but considerably more distributed than shown in Fig. 18 of his paper. I am also of the opinion that the losses in the short-circuited coil under each brush, as represented in Fig. 21 of the paper, by the difference between the curves IV. and V., are considerably too small, these losses being very often larger than any other component loss.

Mr. WILLIAM CRAMP (*communicated*): The chief value of Mr. Creedy's paper seems to me to lie in the fine experimental proofs he gives of the truth of the "circle-diagram" for the series-motor. In the few following remarks my criticisms must not be taken in any disparagement of the value of his work. Mr. Cramp.

I must first explain the cause of some of the defects in the motor mentioned in this paper. It is only fair to do so in order to show how easy it would be to design a better machine.

In the first place the air-gap might have been much smaller. The dimensions as given on p. 79 are, I think, even smaller than in the

Mr. Cramp machine itself. This large air-gap occurred through a works error, the original design having an armature $5\frac{1}{2}''$ dia., and a bore of $5\frac{9}{16}''$.

In the next place the cast-iron end plates (mentioned on p. 40) were adopted in order to enable an experimental machine to be built quickly from standard stampings. In fact, everywhere the motor suffers from being experimental, and from being built up out of standard odd parts of the Crypto Electrical Co.'s direct-current machines.

In my opinion it is quite possible to build a 1-H.P. 25 $\sim$ series motor with a commercial efficiency of 75 per cent., and a fair weight efficiency. I do not, however, think that in these small sizes, and especially for high voltages and lighting frequencies, such a motor can possibly replace the repulsion motor.

Coming now to the results of the paper, though Mr. Creedy points out the value of a large number of armature-turns and high peripheral speed, he does not point out the value of multipolar as compared with bi-polar design. The advantage of the former type arises from two facts: (1) with given length of air-gap and magnetic density the ampere-turns *per pole* are almost constant; (2) with given number of armature-turns and armature current the cross-magnetising turns of the armature are *divided among the number of poles*. Hence a series alternate-current motor should certainly be designed more like a multipolar alternator *with a large number of poles and a wheel-like armature.*

Next I may point out the great importance which the ratio $\dfrac{\text{pole arc}}{\text{pole pitch}}$ may have upon the design of the machine. Nothing is said upon this matter in the paper, and it would be interesting to hear what Mr. Creedy has to say about it. I should also like to say that I find good commutation, with these motors, difficult to attain at frequencies above 50. I think that Mr. Creedy's work in this direction will, if carried further, yield valuable results. I also think that, though Mr. Creedy's change in the Steinmetz notation is most ingenious, and admits of the easy treatment of quantities like power, etc., this result is obtained at the expense of simplicity in the original expressions.

Mr. Creedy. Mr. CREEDY (*in reply*): I am unable to criticise Mr. Schoepf's remarks to any great extent, as they deal particularly with the Westinghouse motor, of which I have no knowledge. I was much surprised to hear that the neutralising or compensating coil on the Westinghouse motor was in series with the armature, as I certainly was under the impression that induced compensation was used. When I stated that a motor could be built for 50 cycles, I was thinking rather of small crane motors and machines of that kind than of traction motors. I am sure we are all obliged to Mr. Schoepf for his information relating to the Westinghouse motor, and wish there were more of it. The angle θ mentioned in my paper is intended as a rough practical method of taking the iron losses into account. Some such method is essential, as in practice the current does not move on an exact semicircle, such as we should get if we neglected θ, but on a circle whose centre, as a rule, will be above the line of zero power-

factor. The angle θ is assumed not to vary as we vary the speed, principally because it seems unnecessary to introduce further refinements into the theory, when this assumption seems sufficient to account for the phenomena observed. I am not in agreement with Mr. Russell's view that this angle is caused principally by the distortion of wave-shape due to hysteresis. As Fig. 13 shows, the flux-wave in the motor tested is very nearly a sine wave. If the flux-wave were seriously distorted, the counter E.M.F. curve in Fig. 14 should also show the distortion. Yet the angle θ was by no means negligible. In motors having a fairly long air-gap, such as may be allowed in the series motor, the hysteresis effects will be small compared with the eddy-current effects to which I attribute the angle θ. Among the eddy currents, at any rate for a first approximation, may be reckoned the current in the coils short-circuited under the brush. If O I in the diagram be the main current, it will induce in the short-circuited coils an E.M.F. O E, which will produce a current O I′ lagging behind it by an angle $\tan^{-1}\frac{Lp}{R}$, where Mr. Creedy.

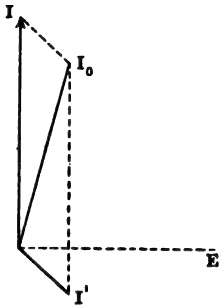


FIG. H.

L = Coefficient of self-induction of short-circuited coil.
R = Resistance " " " " "
$p = 2\pi f$.

The main flux will be produced by O I_0, the resultant of these two currents, and will consequently lag by a constant angle behind the main current. The effect of the other eddy-currents will be similar to that of the current in the short-circuited coil.

I have here entirely neglected the armature flux, which will undoubtedly tend to cause a variation in the angle θ.

While discussing this angle, I may deal with Mr. Punga's remarks on it. Although it does not vary much as we vary the speed, it does vary as we vary the field turns, becoming greater the less turns we put on. This explains the magnitude of the angle θ in Fig. 5, in the curve for 20 field turns.

It is clear, from the diagram, that if θ is large we can get considerable leading currents in the series motor, and that if the resistance is large we shall be able to reach unity power-factor at a lower speed than would otherwise be necessary, since the angle of lag of the standstill current O S (Fig. 2) will be comparatively small. This furnishes the answer to Mr. Punga's inquiry as to why a leading current is obtained. On p. 86, I have suggested a tentative explanation of why θ is negative when compensation is employed. I do not wish to lay much stress on it, however, and I shall be obliged to Mr. Punga or to any one else who will furnish a better explanation. The fact that the angle θ can become negative seems to dispose of the contention that it is due to hysteresis.

Mr. Creedy. The iron losses in my experimental motor are not to be taken as representative of those in all series motors. The iron losses due to rotation were large because the slots were milled out to take an extra number of conductors, and the stampings were burred over, the rotor carcase being thereby partly short-circuited.

I think the question of induced *versus* forced compensation, alluded to by Mr. Calisch, is largely one of cost. If induced compensation be used, the compensating coil can be bar-wound, and will be a very simple affair, not easily injured; while, if forced compensation be employed, the compensating coil must be hand-wound as a rule; it is liable to burn out and it is difficult to replace. The first cost will, moreover, be considerably higher.

Professor Carus-Wilson, I think, has fallen into a slight misapprehension as to the sense in which the term "Electrical Efficiency" is used in the paper. By using this efficiency, one neglects friction and windage and also the core losses due to rotation. The core losses due to the alternation of the flux, however, are fully taken into account, being represented by an equivalent resistance as is, perhaps too briefly, explained in the paper. By the expression "back volts in the field," Professor Carus-Wilson evidently means the E.M.F. of self-induction of the whole motor, not of the field only, but of the armature as well, which cannot be neglected even in a compensated motor.

This being understood, his method of dealing with the power-factor is identical with mine. Equation 2, on p. 50, is simply a mathematical expression for the ratio of the counter E.M.F. of the motor to the E.M.F. of self-induction of the whole machine, upon which, as Professor Carus-Wilson remarks, the power-factor depends (resistance being neglected).

I have discussed the question of rating to some extent towards the end of my paper, which Professor Carus-Wilson has apparently overlooked. My reasons for not going into more detail were as follows:— Having settled what proportions are necessary to obtain good power-factor and efficiency, we can easily settle afterwards, in the usual manner, what size of motor will be necessary in order to obtain the required output without undue heating. If Professor Carus-Wilson will work out a design for a series motor in detail, I think he will find it more difficult to obtain good results without a large number of armature turns than he appears to imagine.

In connection with Professor Ayrton's remarks about the efficiency being greater than 50 per cent. at maximum output, I find that, although no special experiments were made on this point, it is possible to prove this fact experimentally from two of the figures in the paper. In Curve I., Fig. 22, is shown a curve of output plotted against speed. Above it, Curve VI., input against speed is shown. It may be noticed that at a speed of about 2,200 the output reaches a maximum value of about 930 watts. The input corresponding to this is about 1,390 watts, which is much less than double. In Fig. 23 similar results are obtained. The maximum output occurs at 2,400 r.p.m. and is about 670 watts; the input corresponding to this is 930 watts, which is again much less

than double, so that in both cases the efficiency is considerably above 50 per cent. Mr Creedy.

I find Mr. Cramp's argument as to the advantages of multipolar design difficult to follow. He states that with a given air-gap and magnetic density the ampere-turns per pole are almost constant. I fail to see in what way this constitutes an advantage for the multipolar design. However, I see his point as to the armature flux being divided among the number of poles in a multipolar design. Let us, for instance, compare a 4-pole design with a 2-pole design. If the armatures are multiple-wound, the 4-pole machine is less advantageous than the 2-pole machine; for, since the flux per pole is halved, while the counter E.M.F. to be produced remains the same, we shall require twice as many turns between brush and brush. The cross ampere-turns per pole and hence the cross-flux will be the same; but since the turns between brush and brush are doubled, the E.M.F. of self-induction will be doubled. If the 4-pole armature be series-wound, however, the case seems to be entirely different. We now have the same number of turns between brush and brush as in the bipolar armature, but the cross ampere-turns per pole are halved, thereby halving the cross-flux and reducing the E.M.F. of self-induction *per pole* to one quarter. There are, however, four poles in series as against two in the bipolar design. Hence by using an n-polar design with a series-wound armature we reduce the self-induction of the armature to $\frac{2}{n}$th of its value in a bipolar machine. This is a very important point which I must admit I had entirely overlooked. The limit to the increase of the number of poles will arise from the increased leakage obtained with a large number of poles.

I do not think there is any great advantage in using a narrow pole arc, as although we undoubtedly decrease the armature impedance thereby, we also increase the reluctance of the main magnetic circuit, necessitating more turns to produce the given flux and increasing the field impedance.

I do not think it is necessary to discuss at any length the relative merits of the series and repulsion motors, but if, as Mr. Punga states, there is very little difference between them, why was the General Electric Company obliged to abandon the repulsion motor?

As regards the question of efficiency, Fig. 25 is intended to prove that the efficiency *construction* gives sufficiently accurate results. The scale deduced from the result that the efficiency is 100 per cent. at infinite speed is unsatisfactory. This is stated on p. 88 of the paper.

I have read with great pleasure Mr. Punga's remarks on the subject of commutation, as they tend to supplement the paper in one of the points where it is rather weak. I shall await with great interest his fuller publications on the subject. However, as all those who are working at the subject of single-phase commutator motors appear to be getting satisfactory commutation, I cannot help thinking the importance of the subject somewhat overrated. I cannot see how it affects the conclusions as to the methods of design necessary to obtain good power-factor

Mr. Creedy. and efficiency, as we cannot sacrifice either for the sake of the commutation.

In the alternating-current series-motor, the effect of compensation of the armature flux is simply to change the value of the armature impedance. It is obvious that the actual value of this quantity cannot affect the theory, so that the theory developed in the paper is as applicable to the compensated as to the uncompensated motor. The substitution which must be made in the equations of design in the case of a compensated motor is indicated on p. 54.

The President. The PRESIDENT: Before I ask you to give a vote of thanks to Mr. Creedy, I wish to remind you that on the 13th of November, 1884, very nearly twenty-one years ago, Professor John Hopkinson and Professor Adams read a paper on alternating-current motors; and on that occasion I had the pleasure of giving the results of some experiments which had been made at Siemens Bros.' works at Woolwich. Among them was the statement that we had constructed an ordinary series continuous-current motor with laminated poles, in accordance with the directions which Professor Hughes had given in a paper which he read in 1883 on how to demagnetise quickly great masses of iron by laminating them, as is well known now. At that time we worked this continuous-current motor first as a series motor; then we sent the alternating-current in parallel through the armature and through the field magnets; and we also sent the current only into the armature, so that we had there an induction motor and a series motor. But we had at that time, unfortunately, a current, I think, of 80 periods per second, and of course our results were practically nothing; we could not get any power out of these motors. At that time lighting was the great field for the use of electricity, and arc lights would not work with frequencies under, I think, 40 to 50. Therefore we did not think it was worth our while at that time to continue those experiments. You can find what we did at that time in Vol. xiii. of the Transactions of this Institution, and in connection with this paper it is perhaps of historical interest, though it led to nothing. I have mentioned that fact also partly with the intention of cautioning the younger generation not to throw things away in a hurry, and not to despair that circumstances will so alter that seemingly useless things will become useful in the course of time. At that time we did not think it would be possible at all to have central stations with low frequencies, because, according to our ideas then, there would be no want for them at all. That the idea of having big power-stations was not new then, may be gathered from the address to the Iron and Steel Institute which Sir William Siemens delivered in 1877. In the year previously he had been at Niagara, and had considered what a good thing it would be if a power station was made there to distribute power all round, just as has now actually been carried out. Without going further into these matters, I think we have greatly to thank Mr. Creedy for a most interesting paper, which will certainly bear careful study. As Professor Ayrton has already pointed out, there is a great deal more in it than appears on the surface. I ask you, therefore, to give a hearty vote of thanks to Mr. Creedy.

The resolution was carried by acclamation.

Proceedings of the Four Hundred and Twenty-fifth Ordinary General Meeting of the Institution, held in the Rooms of the Institution of Civil Engineers, Great George Street, Westminster, on Thursday evening, April 27, 1905—Mr. ALEXANDER SIEMENS, President, in the chair.

The minutes of the Ordinary General Meeting held on Thursday, April 13, 1905, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members—

Mark Feetham. | Robert Loraine Gamlen.
John Ruffell Salter.

From the class of Associates to that of Associate Members—

Dudley E. Batty. | Charles Richardson.
Norman West.

Messrs. P. W. Freudemacher and H. G. Solomon were appointed scrutineers of the ballot for the election of new members, and at the end of the meeting the following were declared to have been duly elected :—

ELECTIONS.

Associate Members.

David James Barnes. | Alexander Longmuir.
P. D. Cursetje. | James McKerlie.

Students.

Francis Walter Main. | Thomas Clifford Mann,
Charles Percy Nuttall,

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. J. M. C. Matthews and C. E. Wilson, and to the *Benevolent Fund* from Messrs. A. P. Haslam and R. W. Weekes, to whom the thanks of the meeting were duly accorded.

The SECRETARY read the following list of Council nominations for the ensuing Session:—

MEMBERS NOMINATED BY THE COUNCIL FOR OFFICE, 1905–6.

As President.

Nomination JOHN GAVEY, C.B.

As Vice-Presidents (4).

Remaining in Office { W. M. MORDEY.
W. H. PATCHELL.

New Nominations { DR. R. T. GLAZEBROOK, F.R.S.
J. E. KINGSBURY (*for re-election*).

Ordinary Members of Council (15).

Remaining in Office {
T. O. CALLENDER.
S. Z. DE FERRANTI.
F. GILL.
F. E. GRIPPER.
J. S. HIGHFIELD.
H. HIRST.
G. MARCONI.
C. H. MERZ.
C. P. SPARKS.

New Nominations {
W. A. CHAMEN.
W. DUDDELL.
Lieut.-Col. H. C. L. HOLDEN, R.A., F.R.S.
W. JUDD.
G. KAPP.
C. H. WORDINGHAM.

As Associate Members of Council (3).

Remaining in Office { T. MATHER, F.R.S.
A. J. WALTER.

New Nomination ALBERT CAMPBELL.

As Honorary Treasurer.

For Re-election ROBERT HAMMOND.

As Honorary Auditors.

For Re-election { F. C. DANVERS.
SIDNEY SHARP.

As Honorary Solicitors.

For Re-election Messrs. WILSON, BRISTOWS, & CARPMAEL.

The PRESIDENT: You are aware that, under Article 45 of the Articles of Association, any other candidate may be proposed by two members, supported by eight other members, and the name of that candidate may be sent in, together with a letter from him saying that he is ready to accept office. Such nominations should reach the Secretary within seven days of this meeting. If any nominations are then made, balloting lists will be sent out, but if no nominations are received this list will stand for the new Council.

The Address of Mr. B. J. Arnold, President of the Am.I.E.E., on "Alternating-Current Electric Railway Motors" (see vol. 34, p. 229), was discussed in conjunction with Mr. F. Creedy's paper "The Alternate-Current Series Motor" (see page 89).

The meeting adjourned at 9.30 p.m.

GLASGOW LOCAL SECTION.

EARTHING.

By W. W. Lackie, Member.

(*Paper read Tuesday, February* 14, 1905.)

The subjects of earthing and bonding have been prominently brought before the electric light and power contractors of this city owing to the fact that the Electricity Department of the Glasgow Corporation has, for the past six years, consistently refused to connect installations in which a metal sheathing was used as a protection to the wiring and as a means of carrying or supporting the insulated conductors, unless it was earthed at one point at least and electrically connected throughout its entire length.

The author is aware that prior to 1896 many installations were carried with insulated conductors pulled into metal tubes, these tubes being joined together by means of wooden ferrules, each length being thus insulated from the next, and the whole system of piping insulated throughout its length, no attempt being made to earth any part of the tubing. As far as he knows these installations gave no trouble, nor were they the cause of any electrical fire. One does not require to seek far for the reason. The work was carried out in such a careful, substantial and workmanlike manner that the pipes might have been conductors. One is also inclined to think that the insulating rubber used prior to 1896 was better than we are now getting, and, of course, the pressures of supply were approximately half of what we have to-day.

March, 1896, is the date on which were issued the Board of Trade Regulations insisting that the metal sheathing of all cables should be properly bonded across. Prior to that date it was commonly thought that if one had 100 yards of metal-sheathed cable buried in the earth it was earthed, and that there was no further necessity for bonding across from one length of sheathing to the next; 100 yards metal-sheathed cable buried in the ground is far from being properly earthed, and this goes to show how difficult it is to make a proper earth in a city.

An earth has been legally defined as follows: "The earth is an earth, but an earth need not necessarily be the earth." "Earthing" the tubing or other metal sheathing of insulated electric light and power conductors is generally meant to signify that the tubing, etc., are to be earthed to the earth; that is to say, they are to be connected to the general mass of the earth, either by sinking a metal plate and

connecting a wire from the tubing thereto, or by connecting the "earth wire" to a water or other pipe, thus making good contact with the earth by being connected with a considerable amount of other piping buried in the earth.

Gas pipes should not be used as earth connections, as frequently the current which flows to earth when a conductor gets in contact with an earth is sufficient to melt a soft metal pipe; and further, the method of jointing a gas branch pipe of iron to a main gas pipe often does not ensure a good contact between the branch and main, the branch pipe being in some cases insulated by brown paper and white lead. A water pipe is almost universally used for an earth connection.

The rule only referring to earthing and bonding, in the general rules recommended for wiring for the supply of electrical energy, issued by this Institution, is as follows:—

> Rule 12.—Conductors conveying current at pressures exceeding 250 volts must be completely enclosed in metallic sheathing or tubing efficiently connected to earth, and such sheathing or tubing must be electrically continuous throughout its length.

This rule is badly worded, inasmuch as any one might at once assume from it that conductors conveying currents at pressures of 250 volts and under need not have the tubing efficiently connected to earth, and that such tubing or sheathing need not be electrically continuous throughout its length; whereas it is a matter of prime necessity that all sheathing should be electrically continuous throughout, and it is just as necessary that it should be earthed and electrically continuous at 100 volts as at 250 volts or over.

The rules referring to earthing in the General Rules for the Prevention of Fire, and the other rules to be observed in the wiring for the supply of electrical energy, issued by the Glasgow Corporation, are as follows:—

> Clause 35.—All metal-sheathed cables and metal tubes or conduits must be perfectly bonded at all joints and effectively connected together and to earth, by means of an insulated stranded copper conductor equal in area to the conductor within the sheathing, tube, or conduit, but not less than the equivalent of 3/22 S.W.G. This earth conductor, however, need not be larger than 7/16 S.W.G. The earth connection must not be to a soil pipe, rhone, or gas pipe, but to a water supply pipe. This is a most important rule, particularly in buildings where there is a gas supply in compo piping.

> Clause 39.—All electric conductors must be kept away from gas pipes and most carefully insulated from them by a spacing not less than one inch in thickness, of wood, if in dry places, and of tile or other waterproof non-conducting material in damp places. This precaution must be taken, no matter what system of wiring be adopted. Special attention must be paid to clause 35.

One other part of a rule which bears on this subject is—

Clause 43.—All fittings must be substantially insulated from any adjacent metal pipes, joists, columns, etc., so as to avoid contact with them, which might break down the insulation of the lamp-holders. Fittings exposed to the weather or fixed in damp places must have the lamp-holders efficiently insulated from them.

The reason for these regulations is, of course, that the middle wire of the three-wire system in Glasgow, as in other places, is earthed under normal conditions at one of the generating stations, and the fact that should the insulation of a cable in a consumer's premises, connected to the positive or negative main of the three-wire system, fail, or either of these conductors get in contact with the metal sheathing, the latter immediately becomes part of the conductor, and any one standing on a metal or concrete floor, or in contact with anything that is in good contact with the general mass of earth and touching the sheathing, not connected to earth, would get an unlooked for and unpleasant shock, which might cause, and has caused, death. It could also easily happen that, in large buildings where both sides of the Corporation three-wire system are in use, if the sheathing was not earthed and electrically continuous, one length of piping or sheathing might be made alive by coming in contact with the positive conductor, while another length might be made alive by a negative conductor, with the result that there would be 250 or 500 volts difference of pressure between two adjacent lengths of piping. An arc would, of course, soon result, which would ignite any inflammable material. Throughout this paper the pressure of supply is assumed to be 250 volts, and the pressure across the outers of a three-wire system 500 volts. If lower pressures are in use the figures given must be altered to suit.

During the years 1902, 1903, and 1904, thirty-five fires were reported to the Electricity Department of the Glasgow Corporation by the Fire Department, as having been due to defective electric light installations. Two of these were, in the opinion of the Electricity Department, not due to electricity at all. At December, 1904, there were 11,000 installations connected to the Corporation mains, so that the fires are, on an average, one per annum per 900 installations, or in the equivalent of thirty-three watt lamps, one per 60,000 lamps, the total lamps being approximately 700,000. Of the remaining thirty-three, fifteen were due to the melting of gas pipes by a current of electricity, the installation in each case having been carried out with metal-sheathed cables; eight of the fires occurred on installations where the metal piping or metallic sheathing of the cables was not properly earthed; seven were on installations where the iron piping or metal sheathing was earthed. The causes of the remainder have probably no bearing on the subject of earthing, but may be of sufficient interest to be stated here:—

Five were caused by the insulation of the cables having been chafed and consequently damaged by contact with the sharp edges of iron pipe ends.

One was due to a piece of hot carbon falling from an arc lamp upon some muslin goods in a shop window.

Five were due to defective twin flexible conductors.

Three were due to deterioration and defects in switches.

Three were due to wooden casing having been saturated with water.

And one was caused on a wood casing installation where the conductors were not protected, but were lying against a soft gas pipe, and the insulation of the conductor failed.

Perhaps it might be well to point out in passing that the effect of these fires was much more serious in the fifteen cases where soft gas pipes were melted, and the author begs to express the hope that electrical engineers will do all they can to stop the use of this class of pipe for the conveying of gas, and, if possible, see that it is removed from any building into which electric lighting or power is being installed.

Considering, however, only the first fifteen cases, and especially the seven where the metal sheathing was earthed, the fact of current going *via* the gas pipes at all, goes to show one of two things, viz., either that the current flowing to earth and back to the generating station divides up between the one, two, or more paths to earth in proportion to the conductivity of these different paths; or that by increasing the earth connections the current going to earth is increased by the increased conductivity to earth of the earth circuits, or partly both.

Further, it is impossible to test an installation after it is completed, with a view to ascertaining whether the metal sheathing is in itself properly electrically continuous throughout its entire length, and whether the continuity of earthing throughout is not due to the sheathing being earthed at one point by the earth wire run for that purpose, and at another point by means of a gas or other pipe. It may be that for part of the course a gas or water pipe is the bonding or cross-connecting link between two lengths of sheathing (Fig. 1). Take, for instance, a piece of tubing laid across some girders to a lighting point. Suppose the tube is cut at this lighting point and the conductors tapped or looped into a ceiling rose, and that the pipe continues on to another lighting point, but that the joining across the gap at the first lighting point is omitted. Assume also (what is quite likely to be the case) that there is another gas or water pipe running across the same girders at some distance from the pipe carrying the electric light conductors. Such a pipe would put the girders into electrical contact with each other, and no testing would show that the metallic sheathing was not continuous. If an earth were to occur in the tubing going to the second lighting point, the current would go to earth *via* the metal tube containing the conductors and also by the second water or gas pipe, but the whole of the current would travel *via* the water or gas pipe across the gap at the first lighting point, with the probable result that the latter would be damaged.

With the present system of earthing, if one conductor, even in a small branch circuit, comes in contact with the sheathing the current that flows momentarily, but long enough to blow both branch and main fuses, is frequently 250 to 300 amperes, and is sufficient not only to

cut off the whole supply from the installation on which the fault has occurred, but to interfere with the supply to other consumers by causing an unpleasant blink in the light. A momentary short circuit has been reported on several occasions to the mains section of the Electricity Department of this city by the generating section of the

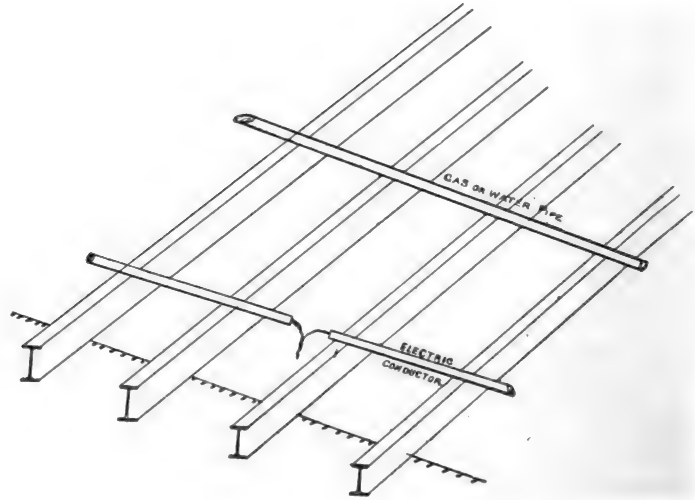


FIG. 1.

same Department, as having taken place in such and such a district, and it has afterwards been found that these short circuits were due to an earth on a three-ampere branch circuit in a consumer's premises. Bearing these facts in mind the author has come to the conclusion that the present method of earthing at any point, and direct, is wrong, and it is his opinion—

(1) That the metal sheathing on installations for connection to public supply mains should be kept clear of all other metal work throughout the entire run of the conductors;
(2) That the connection to earth should be through a resistance of such an amount as would allow not more than, say, two or three times the normal current of the installation to flow to earth in the event of one of the conductors coming in contact with the sheathing; and
(3) That the metal sheathing on installations for connection to public supply mains should be joined to earth at one point only.

Taking these three points *seriatim*, a few words on each of them may not be without interest.

1. Metal Sheathing kept clear of all other Metal Work.

In clause 14 of the Provisional Order granted by the Board of Trade under the Electric Lighting Acts of 1882 and 1888 to the city and

royal burgh of Glasgow, there is a reference to the laying of electric lines, etc., near gas or water or other electric lines, and, in fact, it is distinctly stated that—

> The undertakers (the Corporation of Glasgow) shall not, except with consent, lay their electric lines so as to come in contact with any such main pipes, lines, or services.

If, therefore, it is necessary and proper to keep pipes containing electric conductors clear of all other pipe work underground, it is obviously just as necessary, if not more so, to keep clear of all pipes and other metal work inside buildings.

In the Electrical Installation Rules, issued by the Liverpool, London and Globe Insurance Company, the following are included among the principal sources of fire loss :—

> Leakage of current from metallic armouring or from metal conduits to gas pipes (the gas pipes being thereby melted and the issuing gas ignited).—Clause No. 3.
>
> Leakage of current to earth *via* gas pipes either from charged structural metal work, or from the gas pipes being wrongly used as an earthing connection, and failing especially at the pipe joints in conductivity.—Clause No. 4.

It will readily be seen that if the sheathing used for carrying electric lighting and power conductors was insulated throughout its entire length, even if it were only by one-eighth of an inch of wood, cheap rubber, or fibre, it would be possible to test, after any installation was completed, to see that the cable sheathing was clear of all other metal work in the building, and also that it was in itself electrically continuous. These considerations are most important.

2. A Resistance in the Earth Circuit.

If a resistance was in the earth circuit the rush of current would be enormously reduced and would probably result in only a small branch fuse melting, the main fuse remaining intact, *i.e.*, where the fault or earth occurred in a branch circuit. It would be even a better arrangement if each set of branch pipes had a proportionate resistance inserted to a separate slightly insulated earth wire and the sheathing of the mains had also a resistance as shown in Fig. 2 and Fig. 3.

When metallic-sheathed conductors were first started in earnest it was common practice to have the branch fuses on the distribution-board system of wiring, and the main fuses enclosed in cast-iron boxes, these cast-iron boxes being connected to the metallic sheathing, and consequently earthed. It was then frequently found that when a fuse blew an arc was formed between a conductor and the case, owing to the distance between the bus-bar and the side of the case being less than the break of the fuse and short enough to keep up an arc. Sometimes this arc has melted a hole in the iron box and has also frequently caused the blowing of the main fuse. The remedy adopted by several contractors and consulting engineers was to insulate these cast-iron boxes by mounting them on wooden bases, and to connect the pipes

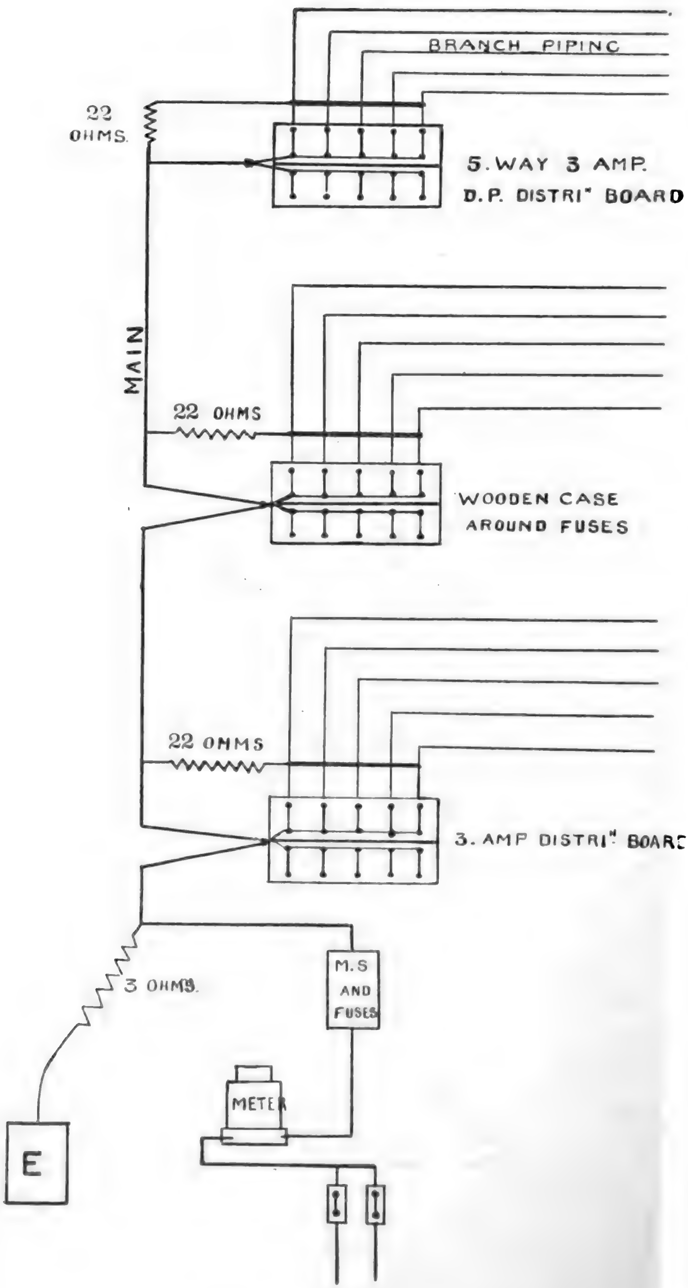

BRANCH PIPING
22
OHMS.
5.WAY 3 AMP.
D.P. DISTRIN BOARD
MAIN
22 OHMS
WOODEN CASE
AROUND FUSES
22 OHMS
3. AMP DISTRIN BOARD
3 OHMS.
M.S
AND
FUSES
METER
E

FIG. 2.

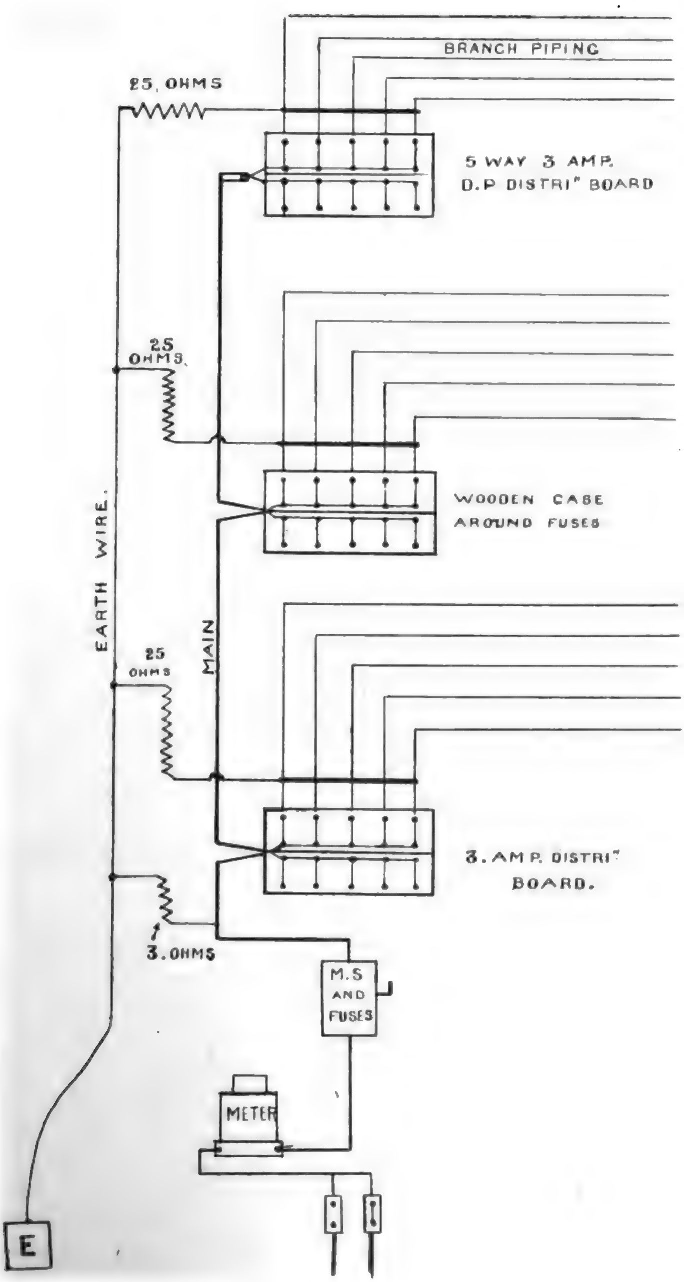

BRANCH PIPING
25 OHMS
5 WAY 3 AMP.
D.P DISTRI" BOARD
25
OHMS
WOODEN CASE
AROUND FUSES
EARTH WIRE.
MAIN
25
OHMS
3. AMP. DISTRI"
BOARD.
3. OHMS
M.S
AND
FUSES
METER
E

FIG. 3.

across the gap by means of a bonding wire, or to have the fuses enclosed in a wooden case. Many makers of cast-iron switches have also been troubled with an arc forming between one of the terminals or blades and the side of the switch-box where the switch-case was of a normal size, and the same course was adopted, viz., to insulate the cast-iron case of the switch on a wooden base and join the sheathing round by means of a bonding wire.

The author is of opinion that if a resistance were inserted in the earth circuit this arcing to earth would be reduced.

One good reason for earthing the metallic sheathing covering electric conductors is, of course, the prevention of possible dangerous shock to the public, and the insertion of a resistance of the size suggested would not militate against this in any way.

Several stations have adopted this course to protect their works from a complete shut-down. To ensure continuity of supply, the middle wire of the three-wire system is earthed through a resistance of a tenth of an ohm, or, in some cases, one ohm. It will therefore be seen that in the event of the positive or negative main going to earth, the maximum current will not exceed 2,500 or 250 amperes, which is less than the available supply.

The method of earthing the middle wire in the Port Dundas Electricity Works in this city is as follows: In circuit with the usual recording ammeter there are ten 200 candle-power 250-volt lamps connected in parallel, which are, however, short-circuited by a fuse. Should an earth connection come on the positive or negative conductor, so that more than 50 or 60 amperes is made to flow back to or out from the generating station, *via* the earth connection, the fuse short-circuiting these lamps goes and the lamps light up. When this state of affairs takes place (let it be said that it is not a normal state) the difference of potential between earth and the positive and negative poles is far from being 250 volts. If an earth of very low resistance comes on the negative, the positive will be 500 volts and the middle conductor 250 volts above earth, and if the fault be on the positive side the negative will be 500 volts and the middle 250 volts below earth.

Mr. Raphael, in his book on *Faults in Electric Mains*, describes a mechanical model constructed by Mr. A. P. Trotter, electrical adviser to the Board of Trade, to show the difference of pressure between each of the three conductors on a three-wire system and earth with varying leakages or earths. A light framework of laths is suspended at the point P (on the accompanying diagram, Fig. 4), and is balanced by a weight W, a cord or another piece of lath bisects the angle A P C, and the three points, A, B, and C, are connected together. A P represents the positive, B P the middle, and C P the negative wire of the three-wire system. If weights are hung by hooks at the points A, B, and C of sizes to represent the conductivity, *i.e.*, the inverse value of the resistance of the earth connection of each of the three wires to earth, the voltage indicated on the scale behind, will be the difference of pressure between each conductor and earth. If the middle wire is earthed through a low resistance—represented by a heavy weight at B

—the difference of pressure between the positive and negative and earth will be 250 volts. If, however, a lower resistance earth connection takes place between the positive and earth, representing a heavier weight at A, then the pressure between the neutral and earth will

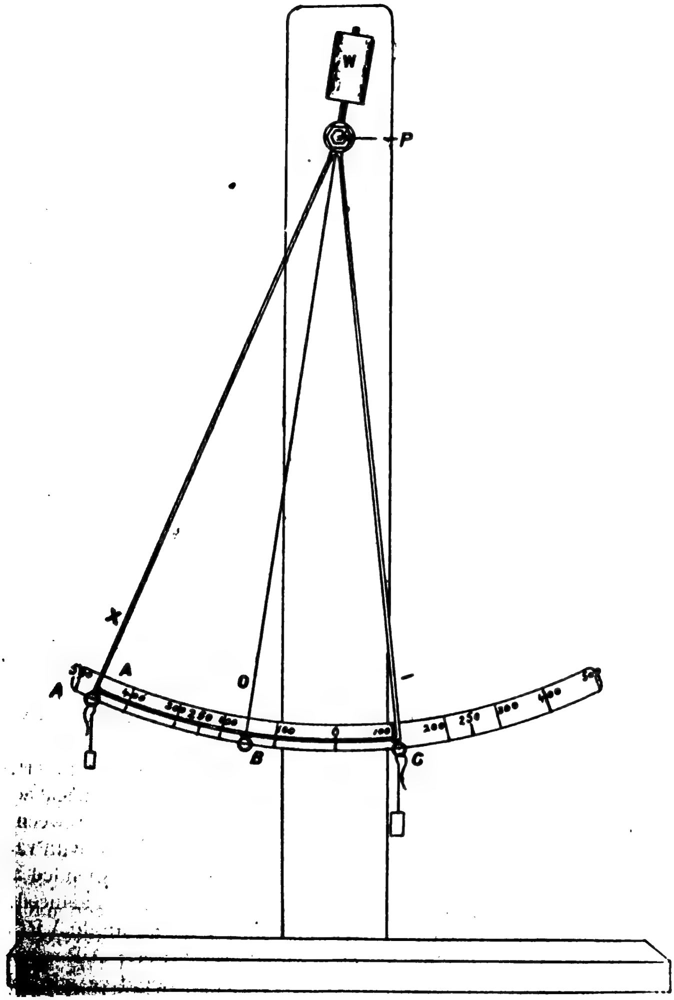


FIG. 4.

approach 250 volts; between the negative and earth, 500 volts. Mr. Raphael says: "Mr. Trotter constructed this model for the purpose of realising and demonstrating mechanically the common expressions, 'rise of potential of a main,' 'fall of potential of a leaky main,' a

heavy leak,' and 'anchoring down or tethering the potential of the middle wire by a heavy earth.'"

The idea of introducing a resistance, to the extent suggested, on the earth circuit, is probably novel so far as wiring is concerned, but to introduce a resistance of some kind is not new in underground mains work, as the Howard Conduit Company, Trafford Park, Manchester, in a pamphlet descriptive of their asphalt conduits for underground mains, advocate this. This asphalt pipe is made with a spiral of iron wire surrounded throughout the entire length of the spiral with ½ inch or ¾ inch of asphalt. The company state that one of the objects of their system is to provide a safeguard against stoppage of supply when the insulation of a cable breaks down.

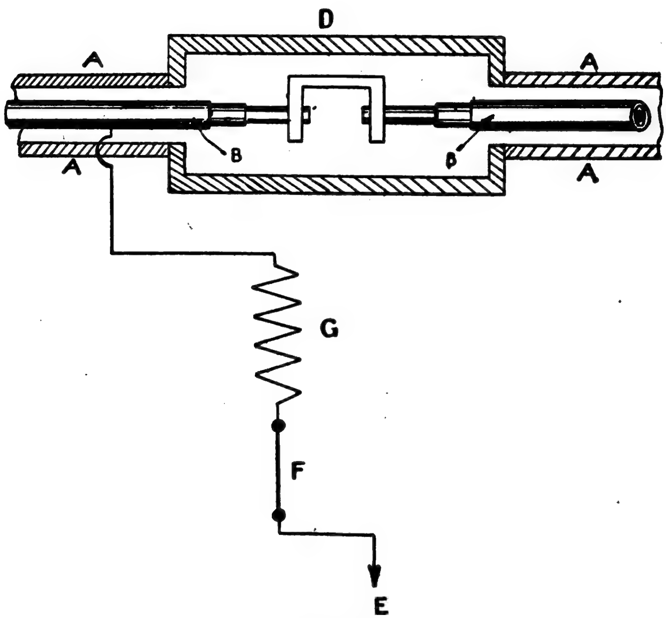


FIG. 5.

The method of connecting up their pipe is shown in the accompanying diagram, Fig. No. 5. D represents an asphalt-lined joint box protecting the connection between two lengths of lead-covered cable B, laid in the asphalt pipe A, the lead of the cable being insulated from the joint box by the asphalt, and the lead covering of the cable is connected to earth at E through a resistance G of 1 ohm, and an indicating fuse F to blow at 25 amperes. The lead of the cable is divided up into sections at the joint boxes. The only path from the lead covering to earth is through the resistance G and the fuse F. In an ordinary case if a failure of the insulation of the cable occurs (causing a short circuit to the lead and so to earth), the cable is burnt out or the

circuit-breakers are opened and the supply interrupted, thus causing considerable trouble. In this system of laying, the fuse F, in the section in which the fault occurs, is blown, and the lead covering is then insulated from earth by the asphalt troughing. The position of the fault is easily located by an inspection of the fuses in the various street boxes without the necessity of making tests or interrupting the supply. The cable can still be utilised until a convenient time comes for repairing the fault. It is also claimed that this resistance reduces electrolytic currents.

If in circuit with the earthing resistance on a consumer's premises there was an electro-magnet, or if the earthing resistance took the form of an electro-magnet, which would close a secondary circuit so as to ring a bell, sound an alarm of some kind, or light a tell-tale lamp, each installation would become self-testing. The winding of the resistance in the form of an electro-magnet would also, in cases of dead earths, act momentarily as a choking coil. We are all agreed that a fuse of a certain capacity affords no protection against leakage current, which is, as a rule, leakage to or from earth, so long as that current does not exceed that at which the fuse will blow. The above arrangement would act before the fuse, and even a simple electro-magnet in circuit with the earth wire without the resistance advocated would always be an advance on present practice. It has frequently happened that for some reason or other the fuse, on the branch main connected to the neutral wire on a two-wire installation (*i.e.*, on an installation connected to one side of a three-wire system), has gone, and the installation has had an earth connection on the same conductor (*i.e.*, the neutral) inside the premises beyond the fuse. The fuse has gone, probably due to this earth. The installation still continues to have a satisfactory supply through this earth connection and the earth connection at the generating station. Such a state of affairs goes on until a time when the positive or negative conductor goes to earth somewhere else, when either the lamps dim down very much or brighten up and probably burst. If a resistance of the amount suggested was inserted in the earth connection, the chances are that the consumer would very soon see that something was amiss, due to the bad pressure brought about by the supply having to come or go by the earth resistance; and moreover, if a bell or other device was connected, as indicated, with the resistance, it would immediately show that current was passing by the earth circuit.

3. Earth at One Point only.

The reason for earthing at one point only is obvious if a resistance is to be inserted in the earth connection. For testing purposes it would be convenient to disconnect the earth connection. If earthed at more than one point several resistances would be required so that the joint parallel resistance should equal a resistance such that only two or, say, three times the normal current would flow to earth; but further current is diverted over the other metal work of the building if

earthed at several points. But even if a resistance is not inserted the fall of potential when an earth current flows is, to a great extent, on the consumer's premises, *i.e.*, it is between the point on the sheathing at which the fault occurs and the earth, and it is not between the generating station and the consumer's premises, nor between the consumer's earth connection and the generating station. If several paths are given between the metal sheathing and earth on different floors of a building, there is current diverted over all the other metal work of the building, and such stray current may cause arcing and fusing sufficient to melt pipes—gas and water—and, if gas, fire will result.

The resistance of the earth part of the circuit may be exceptionally low in Gasgow. If in other cities or towns, or in places where isolated plants are laid down, the resistance of the earth part of the circuits is high, or where earth plates are used, and not the water or other service pipes, the earth circuit may form the resistance now advocated. In Glasgow the earth resistance has been taken between several places. Between the generating station at Port Dundas and Waterloo Street, a distance direct of 1,580 yards, the earth resistance is approximately 0·05 of an ohm.

The circuit from the generating station to a consumer's premises on a three-wire continuous-current system consists of a length of feeder, a length of network or distributor, and a branch. Then follows the consumer's wiring. The feeders used throughout Glasgow are 1 square inch in area, and are of an average length of 2,000 yards, equal to a resistance of 0·048 of an ohm. The network has an average resistance of 0·046 of an ohm, and, taking an average circuit in a consumer's premises at 0·4 of an ohm, or say an average resistance on the live side and of the earth circuit from the earth connection back to the generating station of half an ohm, it means that when an earth current of 50 amperes flows, the full pressure on the feeder, distributor, and wiring up to the fault, and from the earth connection to the generating station, is 25 volts ; with 100 amperes, 50 volts ; with 200 amperes, 100 volts ; with 300 amperes, 150 volts ; so that the fault, sheathing, and earth circuit on the consumer's premises must have a fall of anything between 200 volts and 100 volts. The average resistance of 50 yards ⅝ inch iron tubing with joints has been found to be 0·4 of an ohm, and the resistance of the lead covering of 50 yards of 3–20 twin wire 0·8 of an ohm. It looks from this, therefore, as if the current to earth would equal a considerable pressure divided by the resistance to earth of each circuit, and this may explain the melting of the gas pipes and consequent fires in the seven cases of fire referred to in another part of this paper. On a private installation the maximum power possible through an earth or short circuit is the power of the plant, but with a fault on a consumer's premises in Glasgow there may be the power of the whole electricity works at the back of the fault for the time being.

In installations carried out with lead-covered conductors, the core being stranded, many faults have occurred due to a strand breaking

and making contact with the lead. The contact made has been so good and the current so great for the instant, that the lead has been burned clean off from the point of the broken strand (Fig. 6), and the fuse protecting the circuit has in some places gone and in other cases stood. When it has gone the lead has been melted clear of the strand; testing shows nothing; and the fuse can be replaced. The fuse is inserted and the installation may seem all right again, but sooner or later trouble will be experienced with a conductor in this state. Frequently workmen from the Electricity Department have been sent to attend to a fuse that has gone on an installation carried out with lead-covered wire, and they have replaced the fuse and stated in answer to the query "Cause?" "No cause found." What has just been said might be used as an argument in favour of using solid wires up to No. 14 in place of small wires stranded for lead-covered cables, seeing that the lead covering makes the cable rigid irrespective of what the copper core is. With a resistance in circuit with the lead sheathing to earth, the author feels that the current would not be so great as to melt away the lead at the point of contact with a broken strand of a small cable. If by accident a plumber or other tradesman does come along and runs an earth connection across the metal sheathing, the

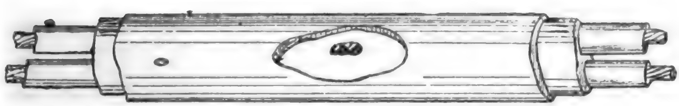


FIG. 6.

installation will be no worse than it is at present, and testing would show this if the sheathing is supposed to be clear of other earths. The current that will flow to earth may be quite sufficient to melt it even if a resistance is not in circuit to earth, whereas if no such earthed connection is run, the installation will be considerably better. May the same reasoning not be used in advocating the introduction of a resistance on the earthing wire from a motor or dynamo? The comparatively enormous damage generally done to a small motor when one of the conductors in it goes to earth, in the opinion of the author, justifies putting in a resistance to limit the current. At one time the author thought of suggesting that in circuit with the earth wire resistance a solenoid might be connected so as to act on the main switch, and switch off the whole supply, but he did not think this would add to the efficiency of the supply. On a motor circuit, however, such an arrangement could with advantage be added to the over-load release. A similar arrangement might also with advantage be put in circuit with the earth wire from dynamos and motor generator sets (when not connected to steam plant), which would indicate, if it did not switch out of circuit, the dynamo or motor. Reverse current cut-outs are now almost universally used on generators, and the writer thinks that in the majority of cases the breakdowns are due to one of the conductors going to earth *via* the earth connection. If therefore

the non-return cut-out had an extra coil added in the earth circuit it would be an extra safeguard. An electro-magnet in the earth circuit to close a bell circuit would certainly be an improvement. There are already many metallic-sheathed installations in Glasgow connected to the Corporation electricity mains, which only require the resistance in the earth wire to put them in line with what is advocated in this paper. The sheathing has been earthed at one point in the basement, and kept clear of all other metal work in the buildings in which they are contained by means of a strip of wood run throughout the installation to which the pipes and cables are cleated. It will be remembered that a paper on underground mains was read in 1902 to this Section, and in the discussion that followed it was made pretty clear that the faults on lead-covered cables were not due to electrolysis, but due to fusion, *i.e.*, melting by excessive currents and arcing. Pieces of the lead covering of underground cables, with holes burned in them, have frequently been shown to the author, and it has been reasoned that electrolysis must have been going on at these points. The author submits that the fragments of a blown fuse might as well be produced in proof of such a contention, and surely no one will say that electrolysis goes on over a fuse. The author believes that these holes in the lead are due to fusion. If proper sized resistances could be inserted in the earth connections on metal-sheathed underground mains, fusion could and would be removed.

The author has been emboldened to put these proposals before this Section, by the fact that what he suggests is not an expensive fancy and will hardly appreciably increase the cost of an installation. A resistance for a 25-ampere installation, viz., a resistance of about 3 ohms to carry about 70 to 90 amperes, will not cost more than thirty shillings, and for a 100-ampere installation two pounds. The resistance need only be one to carry the maximum current for, say, half a minute.

By insulating the sheathing throughout its run, earthing it at one point only, and introducing proper-sized resistance on the earth circuit, we have—

(1) Made it possible to make a further and important test at all times, even after an installation has been completed;
(2) Increased the efficiency of the supply;
(3) Reduced the already small risk of fire from electrical causes;
(4) In no way interfered with the precautions for the safety of the public from shock;
(5) Rendered installations continuously self-testing.

The reason for insisting that fittings and lamp-holders, or lamp-holders alone, shall be insulated is given in Rule 43 of the Corporation Rules in the words, "which might break down the insulation of the lamp-holder." Another and even more important reason is that if the lamp-holders were not insulated they would most assuredly break down the insulation of the lamp-caps in use. Cases are on record where the insulation between the lamp-collar and one of the terminals is nil. All lamp-caps on 250-volt lamps will stand 250 volts between

the two terminals, but few will stand 250 volts between one of the contacts and the metal collar in metal-collared lamps, or the lamp-holder in porcelain or vitrite-capped lamps. Besides, it will have been noticed that in the abnormal state of division of pressure between the positive, neutral, and negative conductors and earth, *i.e.*, when the positive or negative main is to earth, it is quite possible that between one lamp contact and earth, if the holders are earthed, there will be at times a difference of pressure of 500 volts. The lamps in general use to-day are not meant for this, and consequently the simplest and the cheapest way is to insulate the lamp-holders and remove these two dangers.

DISCUSSION.

Mr. JOHN M. M. MUNRO: The paper is so suggestive that one speaker can deal with only a few of the points raised in it. No one will question what is said about earthing to gas-pipes. I fancy that few now earth anywhere except to water-pipes, and to these at a point as near to the main as possible. The whole paper shows that we have yet to find an ideal system of wiring. There are signs that as we progress we may use again some of the methods tried in the early days of electric lighting. Of course, wood-casing is dangerous if it gets wet, and unsightly if not well planned. I need not enumerate its many advantages, but I mention one which has a bearing on metal conduit and lead-covered systems. With wood-casing the potential slope across the dielectric is less steep. In metal conduits the wire coverings touch the tube and each other at many points. In an ideal conduit the tube and the enclosed conductors will not differ widely in potential. **Mr. Munro.**

Mr. Lackie states that only thirty-five "electrical" fires were reported for the three years just past. Considering the variety of workmanship, this shows how essentially safe electric lighting is. How does the ratio to lamps installed compare with the ratio of accidental gas fires to gas-jets in Glasgow?

The first of the two leading suggestions of the paper is that metal sheathing be kept clear of all other metal work in a building. This is easily said, but less easily done, especially in old buildings where tubes have to be pushed below finished floors and plaster. Some new buildings nowadays are nearly all iron. The fact is that architects are to blame for much of the trouble. They not only make no provision at all for the fitting of artificial light, but often render its safe fitting impossible. I have for some time endeavoured to get all tubes for which I was responsible insulated slightly from other metal work of buildings. I found it quite possible—although troublesome and sometimes expensive. An external and really insulating enamel or other covering would be of assistance provided that it did not break in bending, or be a sponge for damp, or scrape off too easily. But multiplied precautions are expensive. It might be cheaper to put an insulated and earthed sheath round each conductor, and so be enabled, through a resistance solenoid and contact in circuit therewith, to

Mr. Munro. control a cut-off fuse, and leave a discontinuous non-earthed metal outer tube to afford mechanical protection only.

As to placing a resistance between ordinary conduits and earth, this adds a little to the trouble of fitting the tubes, for two tubes from one fuse-box may run side by side and touch, but apparently no contact could be permitted between tubes from different boxes, for such contact would reduce the total earth resistance as arranged by Mr. Lackie, and make the device to that extent less efficient. Then, apparently also, any extra resistance between a set of tubes and their proper earth would send a greater proportion of current by other chance earth contacts, if any. Such resistance, therefore, might aggravate the evil which formal earthing is intended to prevent. Under actual conditions this is so, but only to a limited extent. The interaction of the protective devices of tubes from two fuse-boxes would be more inconvenient than dangerous, for every new path to earth—formal or accidental—would find its own current limited only by the resistance of such path and by the fall of potential in the conductors, due to the current.

As to the electromagnetic alarm described on page 119, it would act all right if the tubes were really free and kept free from other effective earth contacts. It would commonly act fairly well, even if other contacts existed. The suggestion made as to fitting a resistance, with or without an alarm or switch-off arrangement, between motor frames and earth is a valuable one, and ought to be enforced. It may be that Mr. Lackie's suggestions may open the way, eventually, to getting rid of the need of permanently earthing the conduits of interior wiring. If we can efficiently insulate our indoor conduits, and guard them with really reliable indicating and protecting devices, it might be wise to omit any permanent earth connection of these conduits. The mid wire might remain earthed at the generating station, but the conduits of internal wiring would be earthed, if at all, only and automatically on the occurrence of a fault in the local wiring.

Mr Newington. Mr. F. A. Newington: Mr. Lackie's paper, although entitled "Earthing," deals with installation work generally, and this is a matter of very great interest to all of us just now particularly, as there have been several serious fires which have been attributed to fusion of electric wires and have brought the matter prominently before the public. If the public get the idea that electricity is unsafe it will very seriously hamper the industry. The chief reason of the slipshod work of piping, such as we saw on the screen at the last meeting, is, I think, competition. Mr. Lackie states that the Electricity Department of the Glasgow Corporation has for the past six years consistently refused to connect installations in which the metal sheathing was not electrically connected throughout its whole length, and I congratulate the Glasgow Electricity Department if that is true; but I have very grave doubts about that. Mr. Lackie draws attention to Rule 12 of this Institution, which says that conductors carrying pressures exceeding 250 volts must be in metal sheathing throughout. This rule, I think, is extremely vague and misleading. From it one naturally sup-

poses that for all pressures below 250 volts it is not necessary to earth the pipes or that they should be continuous, and I believe this has been taken advantage of in certain systems of tubing which are jointed together by sleeves, and this rule of the Institution has been quoted to show that good electrical continuity is not necessary. Clause 35 of the Corporation regulations insists on an insulated earth conductor. I rather believe that it is on record that the fire has been caused by the insulation on the earth wire getting over-heated and becoming ignited. I do not see any use or good in insulating the earth conductor. In the list of fires which have occurred since 1902 in Glasgow, the author states that seven fires occurred in installations where the metal piping was earthed. I should like to have some further particulars about those seven fires if possible. The author draws three main conclusions from his experience and experiments. First, that the metal sheathing should be kept clear of all metal work; secondly, that the earth conductor should be of some resistance; and thirdly, that it should be earthed at only one point. Theoretically I agree with Mr. Lackie entirely, but in practice I am afraid I have to disagree with him, with the present state of installation work. I believe that it is impossible—although the last speaker said it was not—to keep the pipes protecting the electric wires free from other work. As regards the resistance in the earth circuit, if the pipes were clear of all other metal work it would of course be very useful in reducing the flow of electricity, but with other metal work in contact I think it would only make matters worse. I believe that with the present system of work it would be better to earth all the other metal work in the building. Mr. Newington.

Mr. HENRY A. MAVOR: The paper marks a very interesting stage in the progress of electrical work. It is interesting to those of us who have contended that it is not safe to run electric conductors without an earth protection, to find that engineers who have such large experience as Mr. Lackie are coming round to this conclusion in so definite a manner. I disagree entirely with the three essential points that he lays down in page 120, and which sum up the conclusion of the whole matter of his argument. I entirely agree with him as to the necessity of precautions, but I think that he sets about getting them in a wrong way. I believe the right way to get satisfactory work is to insist upon earthing as many points as possible. Taking the other points in order, Mr. Lackie says that the metal sheathing on installations for connection to public supply mains should be kept clear of all other metal work throughout the entire run of the conductors. Now, I am convinced that the proper way to get a safe installation is not to do anything of the kind, but exactly the opposite. I believe a safe way of dealing with conductors is exactly what has been found necessary in lightning conductors, namely, to connect the whole of the neighbouring metal up to the lightning conductors. Formerly it was considered to be necessary to disconnect it. My opinion is that the neutral wire should be treated like the lightning conductor. Mr. Lackie further says "that the connection to earth should be through a resistance of such an amount as would allow not more than, say, Mr. Mavor.

Mr. Mavor. two or three times the normal current of the installation flowing to earth in the event of one of the conductors coming in contact with the sheathing." That would be manifestly impossible, as has been already pointed out, unless the first provision were carried out. Further, the real trouble arises not between one of the conductors and the earth, but between the two conductors. When a flash takes place inside the metal box or other place where fault occurs, the difference of potential which causes great heating is not between one of the conductors and the earth, but between the two conductors. He says, thirdly, "That the metal sheathing on installations for connection to public supply mains should be joined to earth at one point only," but I have already dealt with that. By far the greater part of the electric energy in this country will very soon be distributed through conductors, one of which is definitely connected with the earth at many points. There seems no reason why this should be prohibited on lighting circuits, and permitted on tramway and other power circuits.

Mr. Manley. Mr. J. W. MANLEY: At the invitation of your Secretary I travelled to Glasgow in order to show you the leakage indicator, and if it will interest you it will afford me much pleasure to demonstrate the instrument under actual working conditions. To my mind a simple means, at small initial cost, capable of discovering and making known to the consumer the presence of a leakage, is a desirable thing and should be a part of every installation. With all its drawbacks gas has this particular advantage over electricity, that when a leakage occurs it is known to the consumer; it is otherwise with the latter, and the consumer has no means at his disposal for learning when his installation is out of order, excepting of course the periodical inspection which has been advocated. At the same time the instrument must be of such construction that its working does not interfere with the ideas and regulations of the electrical supply authorities. Objections would, I feel sure, arise from this source if it were necessary to the working of such an instrument to have an earth wire attached as part of such across to the potential mains, or if a current was constantly circulating in the instrument to operate it. The instrument before you requires neither of these conditions to render it operative, the leakage current alone being all that is required, so that unless and until a leakage does occur, the instrument is inoperative. It will be observed that within the glass tube there is a small magnet floating upon the liquid. This floating magnet is kept in central position by a small permanent magnet which you will see situated at the top of the frame. Now when a leakage occurs the floating magnet will be attracted out of its central position to whichever side of the conductor, flow or return, the leakage occurs. The instrument has not the conditions attached whereby notice of leakage is made apparent beyond the indicator itself, but this is, and has been easily done, and it requires no stretch of imagination to discover that by contacts placed in the path travelled by the floating magnet the leakage can be indicated anywhere away from the indicator itself, or an installation or a particular bad circuit can be automatically switched out. In a large installation the best method, no doubt, would

be to have an indicator fixed in each sub-circuit, when a bad circuit automatically cut out would not interfere with the remaining part of the service, but in a small installation, say up to 5 amperes, one instrument in the main cable would be sufficient. The cost of this instrument would not be great, say for 20 or 30 lights a shilling per light added to the cost of installation ordinary. Mr. Manley.

Mr. WILLIAM McWHIRTER: This paper is an important addition to the author's already numerous contributions towards the safer distribution of electrical energy. It has been suggested in this room on more than one occasion that every means should be used to stop the use of soft metal lead pipes both for the conveyance of gas and for carrying electric wires, and the fact that 43 per cent. of the fires reported as electrical in Glasgow during the last three years were caused by contact with soft metal pipes shows the need for this warning. At the same time a stop should be put to the use of conduit with slip couplings, as even the best attempts at bonding are very far from satisfactory, and the fact that one unbonded joint may be serious and the temptation for workmen to leave them unbonded when the tube is erected in awkward places is often too great to be resisted. I maintain that all tubing should be screwed. Some contractors—I do not know why—have a very great love for simplex tubing or tubing of that nature, but I think the time has now come when it should be abolished and only screwed tubing used. It would therefore be well to have the use of such conduit prohibited, and, in my opinion, such prohibition would be warmly welcomed by those responsible for the work. Mr. Lackie's suggestion to earth all conduits through a resistance has much to commend it, and no doubt such resistance would very materially reduce the arcing caused by earth contacts and insulation failures, but unless the fuse inserted was of such a size that it would immediately blow with the current flowing to earth through the resistance, it would be possible to have a greater or less potential difference between the metallic tube and earth. Further, the resistance must be of sufficient size that even should the fuse fail to blow, the temperature of the resistance would not rise to a dangerous extent, otherwise we would have another fire risk added to those we already know, and if this were guarded against by ample sectional area in the resistance wire, then I am afraid Mr. Lackie's estimate of price would have to be very largely increased. The rise in voltage with 70 amps. through 3 ohms would be over 200 volts, and the price of a resistance to safely carry this would not be less than £5. This amount, added to the already keen prices for electrical installation, would make a considerable change, and eventually lead to the use of resistances quite inadequate for the duties required. Certainly an electromagnetic arrangement to trip a switch with a reasonable overload would act equally well and be more reliable, but even this would have to be arranged so that it could not be tampered with. Mr. McWhirter.

Mr. W. A. CHAMEN: I have listened to what has been said, and I quite realise the objections and the dangers, in some cases, that may arise from putting resistance into the earth lead; but after all Mr. Chamen.

Mr. Chamen.

we must be guided by our experience, and we have come to find that the theories that we endeavoured to prove to our own and other people's satisfaction do not always work out in practice. There is no doubt that our older theories of a dead earth may still be right. We have no proof that they are not right. One of our great troubles is that we seldom get such a thing as dead earth at all, and that is the reason why we find it necessary to insulate an earth wire. The reason why we insulate an earth wire is because sometimes it does not make earth, and then it is a source of danger if it passes a gas-pipe. It is better, on the whole, to have it insulated, and the insulation helps also to protect it against corrosion. The great difficulty that we sometimes have with the earthing of metal sheaths is the rush of current that Mr. Lackie has drawn attention to. That is a point that I do not think any of us realise sufficiently. If you get really a short circuit, even although you have comparatively small fuses in that circuit, the moment you get a rush of current it is a very serious matter indeed, and sufficent to cause those blinks that are spoken about. These are things that we have been often unable to account for, but sometimes we find afterwards that some consumer has had trouble with his installation. These faults very often clear themselves and we hear nothing about them at all. When an installation is completed and you have made an attempt to insulate the sheathing but find, by testing, that you have not insulated it, then perhaps it would be very unwise to put the resistance in. I doubt if Mr. Lackie would advocate doing that at all, but that is no reason why we should not make the attempt, and if we do succeed in a new installation in getting the sheathing clear, I think it is no reason why we should not give the resistance in the earth lead a trial.

Mr. Pilkington.

Mr. Basil A. Pilkington: A short time ago I put before the Electricity Department of the Edinburgh Corporation a suggestion for putting electric bells on to the general supply; that is, dispensing with the ordinary Leclanche batteries and using currents at a pressure of 232 to 250 volts. The object is, of course, primarily to reduce fire risks, and at the same time a convenience is obtained in that there is no recharging of batteries to be done. In the fixing of an iron conduit in lighting or power installation a good workman would, as far as he was able, see that none of his pipes came in contact with gas or other soft metal pipes, but I have not yet come across the workman who holds it "as necessary" to prevent the conduits touching electric or mechanical bell wires. Electric bell wires that have been in use for some years become frayed in places, especially if in contact with metal, hence they often form a light, metal connection between an electric conduit and a gas-pipe, and though the wiring installation has been carried out very carefully, fire may occur through bell wires forming, it may be, a second earth, on to a gas-pipe. The voltage of current passing is not so material on circuits up to 500 volts, and as pressures above that are not likely to come into contact with gas-pipes or electric bell wires they may be neglected. The problem is, then, to devise a method of using the general supply itself to work bells, and, as far as possible, to make such arrangements as will indi-

cate to those using the bells when a fault has occurred, be that fault on either "bells" or "lighting circuits." We find that the greatest voltage possible is, by defective wiring allowing to pass through these bell wires, a pressure of some 500 volts. The maximum current passing is then half an ampere, a volume which would hardly be able, even in the most favourable circumstances, to damage a small tin gas-pipe. The defects do not necessarily occur carrying a large amount of current. In a leakage caused through dampness or something of that kind, or even in many other cases, there is a small amount of current passing, not large enough to affect a fuse or destroy hard metal pipes. Mr. Pilkington.

Mr. H. B. MAXWELL: The paper seems to divide itself practically into two parts—the portion of the electric circuit which is on the consumer's premises and that which is outside—and the main objection that appears to me to this system is that it is impossible. In an ordinary dry house it may be possible to insulate the metallic sheathing, but surely this is impossible in a damp place, or where the circuits are carried out of doors. Out of doors they are almost invariably carried in metal tubes. If this method would in any way improve the class of wiring that is done in the present day I should say it would do a great deal. The only possible method of overcoming bad work is for the wiring contractors to give up keeping foremen altogether, and for the electricity department to keep the foremen at the wiremen's expense. The electricity department could then afford to supervise every job, but they cannot do it now. Mr. Maxwell.

Mr. W. M. MORDEY: I am very glad to be able to attend this Section, and must congratulate the author not only on his interesting paper, but on the important appointment which he has received as successor to Mr. Chamen. The author's proposal is new to me. In some ways his proposals reflect unfavourably on the use of 200 or 250 volts. I think this is the only country where such high pressures as 200 or 250 volts are used. In adopting such pressures it must be remembered that in the first place we considered the interests of the supply organisations, and only in the second place the interests of the consumers. In doing so we put a burden on the consumer, justifying our action by giving him a cheaper supply and better regulation. The author suggests that with 200 or 250 volts it is necessary not only to have one insulation, but two insulations in series. If that is true, it to a certain extent justifies some of the objections that were made at the time of the change to higher pressure; it means that our methods of installation are not sufficiently good. While I hope that the author's plan will have a fair and full trial, I must say that my own view is that we should reduce our restrictions and accessories to a minimum, and simplify installations as much as we can. Our supply systems depend for success and growth on making everything as cheap and simple as possible consistent with reasonable safety. Now, are thirty-five fires in three years on eleven thousand installations, or one per thousand per annum, an unreasonable amount? Are we in danger of handicapping our electrical work by putting burdens on the con- Mr. Mordey

Mr. Mordey. sumer's purse that are unnecessary? I ask the author to answer these questions, remembering that his plan would only have prevented a small proportion of the thirty-five fires. I might be allowed to refer to the statement of one speaker, who said that we have no control over those who make the regulations. That view is hardly correct. The Institution of Electrical Engineers is consulted by the Board of Trade and other Government Departments upon questions of regulations in connection with electric supply, and any views put before the authorities as to what we, as an Institution, think is right and best and proper will carry great weight, and will certainly affect such official regulations.

Mr. Rawlings. Mr. W. R. Rawlings: In dealing with the interior section I think there is a liability of an accident arising by placing a resistance in the outer conductor. I believe this is the suggestion made by the author. I do not know how he would prevent earths being made on the outer, as it is sure to be fixed in contact with water- and gas-pipes. To prevent this it would necessitate the outer being insulated. Assume for the moment that the outer conductor is fixed close to some composition gas-tubing, and that the resistance at the point of contact was something lower than the resistance which is inserted, as proposed by the author, I venture to suggest that if a fault occurred the earth would be established at that point, and a fire would result, which I have found in practice, and it occurs to me that by the introduction of the resistance proposed you would interfere with the safety of the earthing system from a fire point of view. I have had some experience with concentric systems, and I am of opinion that the greatest care possible is necessary in establishing a continuous low-resistance earth on the outer conductor, and to be sure of this the system should be absolutely metallic throughout, with soldered joints.

Mr. Perry. Mr. E. L. Berry: There is only one remark I should like to make. I presume that the paper particularly refers to house work and ground work. A friend of mine has had to deal with underground work for eight or nine years, and in every fifty yards he has earthed his lead sheathing, and has made continuous earth from that. He has connected his sheathing, I believe, from one side of the box to the other, and he has taken a piece of $\frac{7}{20}$ cable, connecting same to a copper plate 12″ × 9″, let five or six feet into the ground, and he has packed it with coke, and as a result has hardly a single fault on his mains. In other districts they earth in a peculiar way, such as at St. Pancras, where they work with armoured-sheathed cable, and it lasts for four or five years, but they have to pay attention to it.

Mr. McKenzie. Mr. J. D. McKenzie: The first point that struck me on reading the paper over, was that it seemed to be a pretty conception, but one which would not work for the simple reason that metal-sheathed cables and conduits are being "earthed" constantly through the plaster. I accordingly set myself to find out what the actual resistance between the conduit and the earth was. I did not think that I would get my remarks read and I have not the actual figures, but from memory I think I can give some of the figures that were obtained in three given installations. In two of these the plaster work

was dry, and in the other case I deliberately took the resistance on wet plaster while the plasterers were working at it, and the results I got were as follows. In one case for about 600 feet of conduit—ordinary enamelled screw conduit—the resistance to earth was about 150 ohms. In that case there was a good deal of the piping, I may say, hanging, some of it in air between joists, and some on the lathing above the plasterwork, so that this case can hardly be taken as a fair sample. Where we had 800 feet embedded in dry plaster what we got was 30 ohms approximately, speaking from memory. In the third case where we had 500 feet in wet plaster the result was 19 ohms In each of these cases I instructed the workmen to take all precautions and to insulate the conduit with wood or some other substance, from any iron work in the building, and that was the net result obtained. This shows at once that Mr. Lackie's suggestion of three ohms' resistance is, as far as these results go, quite feasible. There may be other points where the project would fail, because on occasion we have to bore through iron joists to lay tubes, and in that case the insulating of the conduit is a much more difficult matter. Mr. McKenzie.

Mr. J. Johnston (*communicated*): The author's suggestion of a resistance in the earth circuit seems quite a new idea, but the question of earthing seems very difficult of solution, and at present a puzzle to hit upon a system at once safe and effective. Two cases of unrecorded fires arising from earthed systems may be mentioned :— Mr. Johnston.

(1) A motor supplied from Corporation mains at a pressure of 250 volts, fitted in a workshop, with frame earthed to water pipe, flashed over to earth and melted the fuses. The works fireman noticed a blaze at the ceiling of floor below, and a length of gas-pipe hanging down, the gas blazing at the pipe. He turned off the gas and extinguished the fire. The fire was caused by the water- and gas-pipes having been in contact. In the line of the water-pipe, a meter was in circuit with insertion joints at both inlet and outlet, these joints having introduced a resistance of sufficiently high value to cause a difference of potential between the water- and gas-pipes high enough to cause an arc, which melted the pipe and set fire to the gas. This is a case in which a resistance was inserted in the earth circuit, but with what might be termed an *uninsulated* earth conductor.

(2) The second case refers to a system of concentric wiring in which the outer conductor is earthed and continuous throughout. An installation consisting of two gas-engines, belt-driven dynamos and a battery, supplied a building about one hundred yards away, the mains, branch mains and wiring being all concentric with earthed outer. The building had also a gas supply laid on. One night when the lights were nearly all in use, a smell of burning was noticed, and the caretaker found the roof on fire. The fire was got under before much damage was done, and the cause afterwards ascertained. One of the branch circuit leads at the top of the building had been lying alongside of, or been crossed by, a gas-pipe. The mains and wiring generally had been heavily loaded, so that between the dynamos and extreme lamps there had been an appreciable drop in volts. The

Mr. Johnston.

conductor alongside the gas-pipe had probably carried more than its own share of the return current, a portion passing by the gas-pipe back to the main cables at some point nearer the dynamos, so that the gas-pipe and outer conductor were working in parallel. The current at the point of contact must have melted the gas-pipe, or the vibration of the building may have momentarily shaken the two apart. Whichever happened, the resulting arc at breaking circuit melted the pipes, and set fire to the gas, which in turn set the surrounding woodwork on fire.

Taking these two cases into consideration, along with those referred to in the paper, there seems to be everything in favour of the author's suggestion being on the right lines, and it should at least be granted a fair trial.

Mr. Foster.

Mr. L. W. FOSTER (*communicated*): It is very important, in my opinion, to keep all tubing quite clear of other "earths," and it should be sufficient to "earth" at one point only, if one could make sure of metallic continuity. Although some starters will hardly stand it, it is, I think, equally important to "earth" their frames as to earth the frames of motors, particularly crane motors, crane girders, *and* crane rails. The present earthing arrangement is too crude and too violent in its results, and something in the form of a resistance in the earth wire should undoubtedly be used in the future. It is a large and difficult question, and I shall hope to read a long discussion. If Mr. Lackie has only started the ball rolling, he has done many of us a good turn.

Mr. Black.

Mr. JOHN W. BLACK (*communicated*): Mr. Lackie seems to indicate that it is possible for an "earth" current of 250 or 300 amperes to pass momentarily through a 3-ampere fuse, and that that is the reason why the main fuse frequently goes with an "earth" fault on a 3-ampere circuit. I have no definite information on the subject, having had very few instances of such faults brought under my notice, but it seems to me that if, say, a 25-ampere and a 3-ampere fuse are put in series across a 250-volt circuit, the smaller fuse will invariably burn out before the current has reached anything like 25 amperes. If this were not so, what would be the good of putting in fuses proportioned to the various circuits? An "earth" fault on the live wire is practically a short circuit between the middle wire and the "live" wire, and we know that a short circuit ought to blow one fuse only, if the fuses are properly proportioned. I think it will be found that "earthed" cast-iron boxes have been used in nearly every case where the main fuse has gone with an "earth" on a 3-ampere circuit. The branch fuse goes off so violently that an arc is formed to the case, and it is this new "earth" which blows the main fuse. As pointed out by Mr. Lackie, the blowing of the main fuse frequently causes another arc to form to its own box, so blowing the Corporation fuse. I understand that the Corporation fuse-box has, in several cases, been burned out, due to a fault of this sort occurring. Sometimes when the fuses in the branch fuse-box are very close together, one fuse sets off its neighbours, and the current to earth is thus augmented till it is large enough

to blow the main fuse. If well-designed fuse-boxes, with insulated or preferably non-metallic cases, are used, I think it is practically impossible for an "earth" on a 3-ampere branch to do more damage than blow the 3-ampere fuse. Mr. Black.

Now, with all deference to Mr. Lackie, I submit that his proposal with regard to "earthing" is not practicable, and I maintain that the present system, if honestly and skilfully carried out, leaves nothing to be desired. It is practically impossible to insulate permanently the metallic sheathing, unless a complete sheathing of insulating material is used, and this would, of course, add to the cost enormously. He proposes to use a resistance to "earth." The bulk of the current would, under this condition, pass to "earth" by the gas-pipe or other metal touching the conduit, as the resistance to "earth" would be much lower than the resistance of the "earth" connections. The electromagnet arrangement with bell would certainly be useful, as one could impress on the client that the ringing of the bell spells danger, and that the installation must be looked to at once. I quite agree with Mr. Lackie regarding the use of resistance to "earth" for small motors, and I think the proposal to connect this to the overload release an exceedingly good one. There should be no difficulty in keeping the motors clear of other "earths," as, unlike the wiring, they are always in view. The same would apply to large switches, fuse boxes, etc., in C.I. cases.

With regard to lamp-holders, I think all electrical engineers will agree that these are the weakest part of the whole installation. Manufacturers have kept to the standard sizes adopted in the 100-volt days. Why, I do not know, as it is totally impossible to get in the proper amount of space for 250 volts in the standard-holder. I suppose it is too late now to make a change, as an alteration in the size of the holder would cause great confusion, owing to two sizes of lamp caps being required for old and new jobs. Insulating the lamp-holder does not always meet the case. A lamp-holder may be accidentally put to "earth"; for instance, an ordinary pendant may be tied temporarily to a gas-bracket. I have never seen such a fault, but I can quite imagine a fire being caused in this way.

Mr. GEORGE STEVENSON (*communicated*): On reading over the paper, I am sorry to see that Mr. Lackie has dealt almost entirely with lighting circuits, and from that point of view I have no objection to offer to his three proposals, more especially if the wiring be carried out with steel armoured cables. This class of cable is largely used for ship lighting, the armouring in many cases being lightly insulated with a layer of tarred jute, and in my opinion, if proper care is taken, makes a much better job than any of the conduit systems so fashionable at the present time for house and factory wiring. Moreover, if Rule No. (1) is adhered to, the cost would probably be less; at any rate it is less for power circuits. When we come to consider power circuits, however, the proposed resistance is not the only extra item involved. If Mr. Lackie's proposals are adopted, it will be necessary, in cases where the motors are mounted direct on a metal framework Mr. Stevenson.

Mr. Stevenson. making a good earth, to insulate the motor frame from the base-plate. Of course this would not be required in every case, but in crane driving, for example, especially if the crane-post be sunk in the earth, it certainly would have to be done. This means insulating bushes and washers for the holding down bolts and fibre or wood strips which, besides increasing the cost of the job, would make it less satisfactory from an engineer's point of view. Motors direct coupled to lifts and pumps would also require to have the same arrangement, and this, in my opinion, constitutes an objection to Mr. Lackie's proposals. I may say that at the present moment I have some ten 500-volt motors and a 100-kilowatt generator working under conditions much more severe than on a three-wire system with the middle wire earthed through a resistance. These machines are connected to concentric cables with the outer earthed, and as the machine frames are also earthed, the insulation is subjected to the full pressure of 500 volts. The troubles I have encountered have invariably occurred in the starters and fuses—more especially the latter. So far as I have been able to ascertain, a fuse at a reasonable price which will stand a dead short under the above conditions, is not obtainable at the present time.

I am much interested in Mr. Lackie's remarks on faults in lead-covered twin-cables, as my experience has been exactly similar. I do not see how any explanation other than that of fusion is tenable. Concentric cables, however, I have found very satisfactory. In one case (a coal mine) cables of this class have been at work for ten years at 250 volts, and extensions being necessary last October, I raised the voltage to 500, and since then there has not been a single fault on these cables. On page 124 Mr. Lackie says, "Makers of C.I. switches have been troubled with an arc forming between one of the terminals and the switchbox." If he will substitute "users" for "makers," I agree. In conclusion, I venture to assert that if manufacturers of motors and switch-gear for 500-volt circuits paid more attention to this question of insulation, the troubles due to earthing direct would be slight, and Mr. Lackie's No. 2 proposal would be unnecessary.

Mr. Bottomley. Mr. J. T. Bottomley (*communicated*): I very warmly approve of the principles advocated in the paper, and of almost all the suggestions contained in it. The connecting together, metallically, of every bit of the metallic sheathing is absolutely necessary. I approve, also, of a single earth through a moderate resistance. My chief difficulty is the insulation of the metallic sheathing. This may be impossible, or all but impossible, particularly in the case of old houses where the sheathing has to be put in after the house is completely built, and perhaps decorated. In such cases the metallic sheathing must often be pushed down behind lath and plaster. There is often no other practicable way. Insulation of the sheathing may in such cases be impossible, and I can see that there are other cases where the expense of insulating the sheathing may be prohibitive.

Mr. Arthur. Mr. Allan Arthur (*communicated*): In order that a resistance may be inserted between the containing system of an electric light installation and earth, it is necessary that the tubing should be entirely

insulated except at the one point where the resistance is inserted. One disadvantage of having only one earth in a large building is that, in the event of the earth wire being broken, the whole containing system is insulated from earth, or only connected to earth by accident. Another disadvantage is that, if the earthing is in the basement, and a fault occurs on the top flat, all the tubing to the earth is momentarily alive, until the current passing through it blows the fuse; whereas if there be an earth on every flat, only a small portion of that current would travel along the tube, while the most of it would go right to earth on the top flat. I was much interested in the slides showing faults in wiring, but noticed that in every case these faults had occurred with the use of slip tubing, and that there was no precaution taken to bond across the different lengths of tube, etc. About two years ago, when Mr. Chamen read a paper on Electrical Faults before this Section, it was agreed that the meeting would be glad if the Corporation made it a rule that where tubing was used it should only be screwed tubing, and that slip tubing should be abolished. This would prevent faults such as those shown. Where lead-covered wiring is used carefully and installed by men who know their business, I think it makes a very satisfactory job. The idea of having one heavy wire, say No. 14 S.W.G. or 16 S.W.G., instead of a stranded wire is a good one in some points, but would be a disadvantage for looping or making joints. Mr. Arthur.

Mr. L. M. WATERHOUSE (*communicated*): In the early part of his paper Mr. Lackie calls attention to Rule 12 of the Institution Wiring Rules, which states that conductors conveying current at pressures exceeding 250 volts must be completely encased in electrically continuous and efficiently earthed metal conduits. Now Mr. Lackie refers to this rule as badly worded, insomuch as one might assume that conductors conveying current at pressures under 250 volts might safely be enclosed in metal tube which was neither continuous or earthed. I think it is reasonable to suppose, taking into account the long consideration given to the revision of these rules generally, that this rule in particular received special attention at the hands of the Committee, and I do not think we are justified in assuming that it is badly worded; the question arises—was it not intentionally so worded, possibly for the reason that a very large number of installations had been erected with tubing that was neither electrically continuous nor earthed, and that the percentage of such installations that were found unsatisfactory was a very small one indeed? I am unable to agree with Mr. Lackie that it is just as necessary that conduits should be earthed where the pressure of supply is only 100 volts as in cases where it is 250. Mr. Waterhouse.

With reference to the Glasgow Corporation, Rule 35, I shall be glad to hear Mr. Lackie's explanation why he should limit the size of the earth conductor in any case to a No. 7/16 wire. My own opinion is that the sectional area of this wire should be in proportion to the fuse protection of the largest conductor in the conduit which is earthed by it.

Mr. Waterhouse.

Mr. Lackie shows a large proportion of fires due to electrical causes to have originated from the melting of compo gas-pipes by a leakage current, and I can confirm this. No doubt care ought to be exercised in installing a metal tube system in any building which contains compo gas-pipe, as fires so started are urged with dangerous rapidity. From the figures quoted, 50 per cent. of the fires which had an electrical origin were due to the melting of compo gas-pipes; of this 50 per cent., practically 25 per cent. occurred on systems which were intentionally earthed, and 25 per cent. on systems which were not earthed; this, I think, conclusively shows the fallacy of the prevailing idea that continuity and earthing of itself affords security against fire risk.

Lamp-holders.—The Institution of Electrical Engineers' Rules, and those of the Glasgow Corporation, insist on the insulating of lamp-holders, and Mr. Lackie gives us his reason for this. On the other hand, in a Board of Trade circular sent me on October 15, 1904, headed "Factory and Workshop Acts, 1901," I find the following:—"Rule 5. All metal holders for incandescent lamps . . . shall be efficiently connected with earth." This is a point on which there is considerable diversity of opinion, and something ought to be done in the way of uniformity. My own views are strongly in favour of earthing lamp-holders on all installations where continuity and earthing are arranged for at all other parts.

Mr. Munro.

Mr. D. S. MUNRO (*communicated*): The suggested method of earthing through known and limited resistances is, I fear, too ideal to be universally applied. There are many practical difficulties in the way of getting a single earthing point on electrical tubing, as most modern buildings have so much metal in their construction. Not only is the main framework of steel or iron, but lattice steel and pierced cast-iron slabs are to a great extent replacing wood laths and brick partitions. These are often but thinly covered with plaster in which electric wiring conduits are embedded and metallic connection therewith is unavoidable, unless the tubes and boxes are thickly covered with insulating composition. Apart from the difficulty of getting a suitable covering, the increase of outside diameter is objectionable, as with iron behind, it is almost impossible to cut out extra depth to make up for deficiencies in the thickness of plaster. Even the wall surfaces are often covered with sheets of iron enamelled to represent tiling, and in spite of wood blocks or strips, metallic connection with the tubing or fixtures takes place through screw heads, etc., or where the tube pierces the wall. These impediments are not insurmountable, but in many cases they cannot be got over in such a way as to please the architect or whoever is responsible for the appearance of the walls.

Mr. McGibbon.

Mr. DAVID McGIBBON (*communicated*): As a workman of long experience, having worked all the different systems used in Glasgow since electric light was introduced, I am thoroughly confirmed in the opinion that an installation of electric light in tubing, well bonded together and earthed as much as possible, is the perfect system for the

prevention of fires in buildings from electric leakage. We must adopt a system of installing electric light in buildings so that it will be safe to lay across or alongside gas, water, or any other pipes, and have no special cares or favours. I quite agree that connecting to a gas-pipe is dangerous, owing to the resistance caused by the couplings, etc., but it is a well-known fact that electricity will fly to earth by the easiest road to get clear of the building. Earthing to a water-pipe is a very risky and unfinished system. An electric installation should come clear out of the building on its own feet, and not be helped out by the plumber's water-pipe. I would propose that the Corporation run an earth wire into each building along with their service. I think this is quite possible, and they could test the resistance and continuity of the electric tubing by it. **Mr. McGibbon.**

Mr. D. G. Brooks: At the last meeting Mr. Lackie showed us on the screen some examples of how conduit wiring should not be done. If the consulting engineer or party responsible had insisted on the wiring being done after the tubing was erected, such scamped work would have been impossible. Earthing of tubing systems is certainly most important with the high voltages at present in use, but while insisting on this being properly carried out, engineers should be more particular in regard to several details. To mention one, split tees are much used locally with only one lug on the top. These tees are bad mechanically, as it is practically impossible to grip the tubing properly at each end, and consequently when such fittings are used there will often be a break in the continuity of the run. I have placed a sample of the correct form of tee on the table for inspection, and also a sample of the new Simplex contact-nipple system, which will, I think, prove to Mr. McWhirter that it is possible to get perfect electrical continuity with unscrewed tubing. **Mr. Brooks.**

Mr. W. W. Lackie (*in reply*): I feel that I have already monopolised two evenings, and must therefore make my reply as brief as I possibly can. It was suggested by Mr. Munro that in the next paper I contribute to the Institution I might present a list of local electric fires and their cause along with the names of the contractors who carried out the installations involved. This would certainly lead to a over-heated discussion. If any official in the Corporation service finds life not worth living he might undertake this task. Mr. Munro has found it possible although troublesome to insulate slightly the tubing from earth, and towards the close of last evening's discussion Mr. Mackenzie gave most valuable figures showing that this could be and has been done. If dampness, whether it be in plaster, stone, or wood, is the only earth path, a further metallic earth connection should most certainly be made, as one can never be certain that the dampness will remain; and of course I need not point out that damp plaster work or damp stone work, or even damp wood casing will not catch fire. The Board of Trade were perfectly right in insisting that the middle wire should be earthed at one point only, and earthed in such a way that the earth connection could be removed if required. I am glad that Mr. Munro agrees with me that each new path to earth will pass current equal to **Mr. Lackie**

Mr. Lackie. some pressure divided by its resistance, and that he admits we are not dealing with a limited current and that this current will divide itself inversely as the resistance of each path. The time taken to make our insulation test at Port Dundas each week is about half an hour. The positive or negative main is earthed through a resistance, and the current carefully taken on the middle wire of the feeders before and after the earth is made.

I have to thank Mr. Newington for his practical remarks. Our inspectors regularly make a test at the switches with a lamp to see that the tubing is earthed electrically, and to see that the switches are on the proper main; but of course they cannot make any test under the present wiring arrangements to see that it is earthed in itself and continuous as I indicated, partly by gas or other pipes, and partly by itself. Mr. Newington does not see the use of insulating the earth wire. I have heard of one or two fires due to the earth wire having been left bare, melting gas pipes, and it appears a little inconsistent to have a bare wire running for some length across a basement or cellar which will be called upon at certain times to carry considerable current. Insulating the earth wire has also the advantage that it is readily distinguishable for the earth connection from telephones and bells. Mr. Newington pointed out that if electrical contractors did their work as suggested in the paper, an installation might be all right at first, but the first plumber or bell-hanger that came along would be certain to run his pipes across the metallic sheathing and then the state of affairs would be as bad as ever. Several other speakers make practically the same objection. One of my main contentions is that if the plumber or the bell-hanger does put his pipe in contact with the sheathing of electric conductors, there is absolutely no means of testing that this is the state of affairs with the existing wiring practice, whereas if the tubing was known to have been originally clear of all other metal work, it could be tested after the plumber had finished, to see whether or not his pipes were in contact with the cable sheathing. I have already stated that all fire insurance companies both in this and other countries insist on metal sheathing being kept clear of gas pipes, and there is absolutely no electrical difference between sheathing being in contact with a gas pipe and its being in contact with an iron beam or girder with which a gas pipe is in contact.

I am of course very sorry that Mr. Mavor does not agree with my conclusions, for he is responsible for an important part of my early training. Mr. Mavor draws the conclusion from my paper that I am coming round to the opinion that it is not safe to run electrical conductors without an earth protection. I am most assuredly not coming round to this conclusion. In our early underground work in Glasgow we started by laying lead-sheathed cables in iron troughs, but we are now definitely convinced that this is quite a mistake. Trouble has been experienced with arcing and fusion between the lead sheathing and the iron troughs, although both were bonded at every manhole when the lead got alive by accident. The two alternatives were presented to us, namely, either to use metallic sheathed cables and put

them inside a non-metallic box, such as wood, or get a non-metallic sheathed cable and put it inside an iron box; in both cases running the box up solid with compound of some kind. Fortunately for us we have now got a non-metallic sheathed cable, and at present it is run up solid in a wooden box with absolutely no metallic sheath or earth protection, and is proving most satisfactory. The current returning by the tramway rails is not the same as the current that flows when an earth takes place on an electric lighting or power installation. In the case of tramways it is a fixed current and will divide up in proportion to the conductivity of each path; but as a matter of fact the tramway rails need not necessarily be "the earth" but are "an earth" of their own. The London County Council have put down an insulated positive and negative, and I believe other tramway companies and corporations would do the same if they could afford to do so. Mr. Lackie.

I have to thank Mr. Manley for the trouble he has taken in bringing his leakage detector before this meeting.

Mr. McWhirter has very rightly stated that we should abolish Simplex tubing of the light gauge and use proper screwed tubing. The rules of the American Institution of Electrical Engineers distinctly state that the iron tubing used for protecting electric light conductors shall be of a certain gauge which practically corresponds to our gas barrel. The cost of a resistance such as Mr. McWhirter expects would be required to carry 70 ams. with a pressure of 200 volts I think would be more like £25 or £30 than £500, but I would like to point out that if a consumer gets into the habit of inserting larger fuses in faulty circuits, until he gets one that will stay, no system of "earthing" will prevent harm coming to that consumer's wiring. With regard to the breakdown in lead-covered wire I think Mr. McWhirter has not realised that these faults have occurred in small branch cables of 3/22 and 3/20 size. Similar faults do not occur in larger cables. Small stranded wires in being tinned are hardened and become brassy; and as a matter of fact I have seen a length of cable opened which has broken down in the way suggested, and in several other places broken strands have been found, but they had not yet penetrated to the lead.

The remarks of Mr. Chamen are practical and to the point. I know there is one class of engineers who say "earth, earth everywhere," and another class who say "insulate, insulate everywhere." I personally think that a neutral course can be steered, and each place to be wired should be dealt with according to the nature of the premises, and no hard-and-fast rule can be laid down which will be equally applicable to all kinds of premises.

The possibility has been brought before us by Mr. Pilkington of using the electricity supply for working electric bells. It does seem sometimes a pity that it is necessary to charge up batteries when such a supply is available. The only drawback I see is the risk of shock from bell pushes, which are not as a rule so highly insulated as tumbler switches, and cases of shock with the latter are not uncommon.

I cannot agree with Mr. Maxwell as to the impossibility of carrying out the suggestions made in my paper. The metallic sheathing laid in

Lackie damp places and in circuits carried underground out of doors will not cause fire, and is really not earthed in the way that metallic sheathing is earthed when it is connected to a water supply main. I do not take Mr. Maxwell seriously when he suggests that the contractors should stop keeping foremen. The Electricity departments have something else to do, and by spending more money superintending and inspecting the wiring of consumers' premises, they are only making the consumers who employ good and reliable contractors pay for the cost of supervising cheap and inferior work. I am of opinion that by keeping what Mr. Maxwell calls our fourth conductor insulated throughout its run, we have only one-third of the work for the outside testing department; for if this one conductor is right the other three are bound to be right.

Mr. W. M. Mordey has made some very valuable remarks, and he points out that in other countries the voltage still stands at 100 to 120, but I do not agree with him that when we raised the pressure in this country to 200 and 250 volts, we did this in the interests of the Supply Authorities only, and not primarily in the interests of the consumers. I am certain that had the Glasgow Corporation stuck to the old 100-volt supply, their capital expenditure on mains alone would have been half a million more than it is to-day, and the consumers would have had to pay for this. Mr. Mordey is inclined to think that 38 fires in three years on 11,000 installations is not an unreasonably large number; but one must remember that the whole 11,000 installations are not all done in metallic sheathing, and when a fire having its origin in some flaw in the electric wires or fittings does take place, it is very detrimental to the electric lighting industry generally.

I have to thank Mr. Mackenzie for the trouble he has gone to in making some actual tests of the resistance to earth of some metal sheathed cables or conduits buried in damp plaster. Mr. Mackenzie is an advocate of concentric systems, and thinks that all trouble would be removed if concentric cables were universally used. I feel confident that if a concentric system were used the enormous rushes of current we would probably have when a fault occurred, would not only melt soft gas pipes but iron pipes also.

Mr. Brooks gave a communication from Mr. Waterhouse, of the Simplex Steel Conduit Co. I do not think that Rule 12 of the Institution Wiring Rules was ever meant to be retrospective, and I think that nearly every one agrees that Rule 12 is badly worded. The reason for limiting the size of the earth conductor to a 7/16 wire is that installations are as a rule divided into a number of 100 ampere circuits, and a 7/16 copper wire will carry 1,000 amperes without serious injury for a sufficient length of time to allow 100 ampere fuse to blow. Mr. Waterhouse agrees that continuity in earthing of itself does not afford all the security from fire risk that one could wish; and I agree with him, and suggest that what we further require is that the iron piping be kept clear of all other earths.

Mr. Johnston asks if the Electricity Department take any means of ascertaining if Clause 39 of their Rules is carried out. I say most assuredly, Yes, but the matter to a great extent lies with the contractors

and their workmen, for many installations are wired and houses furnished, carpets laid down, and then an application is made for a supply of current. Mr. Lackie.

Mr. Foster says it is very important to keep all tubing clear of other earths, and it should be sufficient to earth at one point if one could make sure of metallic continuity. The proposal in the paper will make it possible to test whether the tubing is clear of all other earths and continuous, and what I wish is to make the tubing its own earth inside the premises without using other earths that were never put there for the purpose of conveying currents.

The 250 volts have to be got rid of some way. Mr. Mavor's proposal is to have 2,500 amperes through 0·1 ohm. The present practice is 250 amperes through 1 ohm. My rough suggestion is 100 amperes through 2·5 ohms. What I consider best of all is 10 amperes through 25 ohms. The shock will be as great if a consumer sees the action of 2,500 amperes on his metallic sheathing as if he got a shock of 250 amperes. This enormous current would probably melt iron gas-pipes, and our last state would be worse than our first. We will get a rush of 2,500 amperes if we use copper sheathing in place of iron, or iron of eight or ten times the thickness, and then probably we will get rid of the chances of electric shock but will also get rid of the supply.

Mr. Stevenson has thrown out a valuable hint regarding the covering generally to be found on steel-armoured cables. I would not suggest that motors on cranes should be insulated from their bed-plates with insulating bolts, &c., but Mr. Stevenson might measure the resistance to earth of the motor erected without any further attempt to earth it. Suppose the motor is one taking 50 amperes at 500 volts, if the resistance is 1 ohm, leave it alone and this will be the resistance required; if greater make an attempt to earth further. The question of circuit breakers *versus* fuses is beyond the scope of the paper, and is a subject for a paper by itself.

Mr. Black doubts the blowing of the two fuses of different sizes in series on a dead earth. Theoretically they should not but practically they do for three reasons :—

1. A 3-ampere fuse has shorter break, and consequently the terminals come in fusing time.
2. The relative radiating surface of the 3-ampere fuse is much greater than that of the 25 amperes.
3. The main fuse is probably slightly warm, and so has got ahead, as it were, of the branch fuse which is cold.

Length of break same for all fuses.

If the user on an average installation continues to put in fuses on a faulty circuit until he gets a heavy enough one to stand, no method of earthing will be an improvement on that installation, and I certainly think it is better to be warned that something is amiss with the wiring by a telltale bell or lamp than by the fire brigade at your door.

Mr. McGibbon is of opinion that bonding would prevent electric leakage, and that earthing should be carried out everywhere possible. I have already stated that every insurance company and supply

Mr. Lackie. authority in this country and abroad have agreed that it is dangerous to lay piping containing electric conductors in contact with gas-pipes. Of course I do not agree with Mr. McGibbon that the electricity would fly to earth by the easiest road. It would fly to earth by *each* road, in proportion to its resistance. I am inclined to agree with Mr. McGibbon that every electric installation should come clear out of the building on its own feet, and that the earthing should be *viâ* the cable sheathing and not by other metal work, and that an earth plate clear of all other metal work and water pipes should be sunk for each installation; but I do not see that the Corporation should be put to the expense of running an earth wire throughout the city for this purpose, and it would not in my opinion facilitate testing in any way.

I have to thank Mr. Steele and his staff in the Electricity Department Laboratory for carrying out many tests for me.

At the conclusion of the discussion the Chairman proposed a hearty vote of thanks to Mr. Lackie for his valuable paper, which was carried with acclamation.

NEWCASTLE LOCAL SECTION.

NOTES ON SOME EFFECTS IN THREE-PHASE WORKING.

By W. M. THORNTON, D.Sc., Member.

(*Paper read February 27, 1905.*)

§ 1. INFLUENCE OF CABLES ON TRANSMITTED WAVE-FORMS.

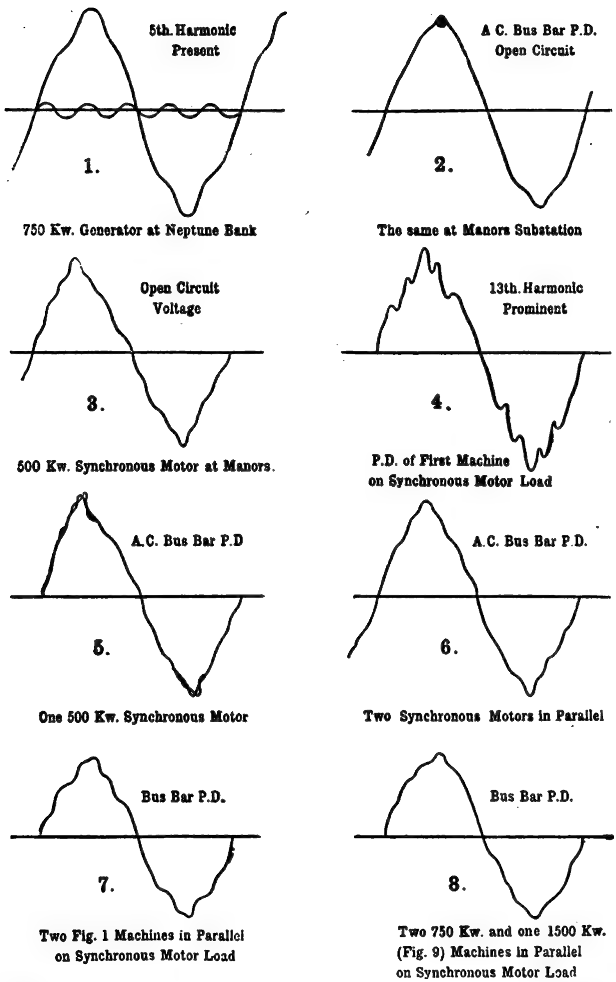
The behaviour of a polyphase electrical transmission system under working conditions presents many interesting problems. Through the kindness of the Newcastle-on-Tyne Electric Supply Company I am able to give the results of some investigations with the oscillograph which were undertaken with the object of deciding, for this particular system,* a few questions of importance in the regular working of the plant. The interest of the curves lies in the fact that they were taken under working conditions, in the absence of any abnormal phenomena, in the comparisons between different machines, and in the addition of a few more facts to our knowledge of polyphase working on a large scale. The tests were suggested by Mr. H. C. Leake and Mr. W. B. Woodhouse, and the details were in their hands throughout. They were taken in three sets—in December, 1901, March, 1902, and July, 1903.

From the curves recorded I have selected those which throw light upon points of more than local interest. For example, it was desired to know whether the wave-forms at the sub-station were distorted by the mains. Fig. 1 is the voltage on open circuit of a General Electric (U.S.A.) 5,500-volt 750-k.w. three-phase generator taken at the Neptune Bank power-house. Fig 2 is the same wave at Manors sub-station, a length of three miles of three-core cable intervening. Analysis of the first curve shows that there is present a strong 5th harmonic. This machine has one slot per pole per phase, and, as is well known, six slots per period give rise to 5th and 7th harmonics in the voltage. Here the former predominates. It is clear from the second curve that there is little distortion by the capacity of the cables; the tops of the waves are slightly more pointed, but there is no fear in this case of trouble arising from sustained resonance.

* For a description of the Newcastle-on-Tyne Electric Supply Co.'s System, see *The Electrician*, vol. 47, 1901, and *Journ. Inst. Elec. Eng.*, vol. 33, pp. 696–747, 1904.

§ 2. Influence of Synchronous Motor Load upon Wave-Form.

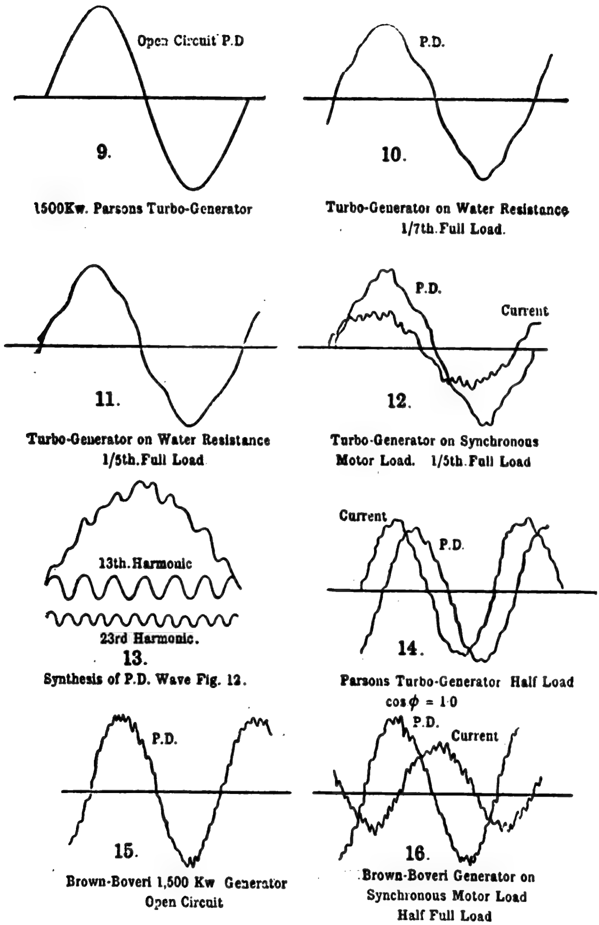
There is, however, the possibility of danger arising from the synchronous motor waves if they have strong harmonics. Fig. 3 is taken from a 500 k.w. motor-generator set at Manors, driven from the



Figs. 1 to 8.—Voltage Wave-forms of Three-phase Machines. R.M.S. Value of each Wave, 5,500 Volts.

direct-current side as a three-phase generator on open circuit, and is typical of all the motors in the system. The machine has two slots per pole per phase, causing a well-marked 13th harmonic. The generator curve (Fig. 4) is the power-house wave of the same machine as

in Fig. 1, but running on a synchronous motor load at Manors. Although in this generator the 5th harmonic is most pronounced, its voltage now appears with a 13th prominent, more marked, in fact, than on the motor, an effect possibly due to the mains, but more likely to the double-frequency phenomena explained in the next section. In Fig. 5,



FIGS. 9 TO 16.

which is the 'bus-bar voltage at the sub-station when one synchronous motor is running light from the alternating-current side, the ripples are smoothed out. In Curve 6 the superposition of the 6th and 13th is clearly seen.

Another proof that the ripples came from the reaction of the synchronous motors is that they appeared to run up and down the curve in time with the engine driving the generator. If they had

arisen from this machine they would have been fixed, but since its phase is swinging slightly, by reason of the engine irregularity, with respect to the circuit voltage, they move along the wave, the amount of movement indicating precisely the range of the relative phase-swing between generator and motor. The visible motion is slight on account of the small scale of the curves, or this would be a suitable method of measuring phase displacement between machines, either motors or generators, in parallel, having somewhat different wave-forms, by observing only the 'bus-bar voltage. In Fig. 5 the tips of the curves waved to and fro in time with the engine. The relative movement of the machines in this case corresponds to 17 deg. of phase, the mechanical movement depending on the diameter and number of poles on the rotor of each machine.

Even when several generators are in parallel, as in Figs. 7 and 8, the motor harmonic is able to make itself felt at the power-house, though less so as the number of machines is increased.

A still better example is the reaction upon a Parsons turbo-generator. This machine gives a very fine curve (Fig. 9) on open circuit. It has, however, two slots per pole per phase, and the 13th harmonic is now just visible in the generator wave. On a water resistance (a circular brick tank, into which dipped three iron plates, rigidly connected and raised or lowered together by a single pulley), there is some distortion, which increases with load (Figs. 10 and 11). In this case, however, it is the 11th harmonic which appears, suggesting that the occurrence of either harmonic is a question of armature reaction. Fig. 12 shows the wave-form of this machine on a synchronous motor load, and there is now a pronounced 13th harmonic. The current is full of a 23rd harmonic. This cannot readily be seen in the voltage, but a wave (Curve 13) may be built up of a fundamental 13th and 23rd, which approximates in wave-form to that of Fig. 12. As the load increases the higher harmonics predominate (Fig. 14).

That these high ripples do not entirely arise from double-frequency effect of armature current reaction may be seen from Fig 15, taken from a 1,500-kw. Parsons turbine Brown-Boveri generator set on open circuit, the machine having four slots per pole per phase. In this curve a 23rd can be counted. When the machine is on load there is a strong 23rd harmonic in the current wave (Fig. 16).

§ 3. Presence and Origin of 23rd Harmonic.

The presence of this high harmonic of large amplitude in normal three-phase working has not, I believe, been previously observed. Since it appears in open-circuit voltage, it must arise in the movement of the magnetic lines across each slot. Every line is first retarded by the slot, then suddenly snaps across it. The voltage induced in the wires within the slot is, therefore, not sinusoidal, but of the following form (Fig. 17), the zero line being taken to cut off equal areas above and below. This wave-form can be produced by the superposition of two curves, one twice the frequency of the other, as shown at *b* ; so

that, since by the mechanical motion of the poles the first distorted form *a* is produced, the result on the main voltage will be two ripples, corresponding, in the case of a machine with two slots per pole per phase, to 12th and 24th disturbances, *both of which must always occur.* Their magnitudes depend upon the relative reluctances of slot and air-gap, a short gap favouring the production of the higher harmonics. A low flux density in the teeth, giving them higher permeability, and so causing the lines to be held by them a little longer, may also be a source of these high harmonics. Their greater prominence in the Brown-Boveri generator is probably aided by the surface winding of the magnet rotor and a low density in the armature teeth. The practical importance of this is that in a wide network of mains trouble is much more likely to arise from machines with short air-gaps or low saturation on account of this high harmonic. In addition to which, every harmonic increases the "copper" loss in the circuit.

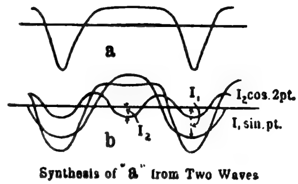


FIG. 17.—Voltage in Exploring Wire Passing Slots and Teeth.

The effect of harmonics upon cable losses is a matter for further investigation. Steinmetz has found that dielectric hysteresis follows the same law as that in iron, the energy loss per second being proportional to the frequency and to the 1·6th power of the voltage. Thus if there are two similar wave-forms, one having one-twentieth the amplitude of the other, but 23 times its frequency, the loss from that with higher frequency will be as much as 20 per cent. of that from the other having 20 times its amplitude.

§ 4. CURRENT WAVE IN UNDER-EXCITED GENERATOR.

As an example of the effect of under-excitation upon the output current of a machine running in parallel, Fig. 18 is given. This is the current in one of the windings of a turbo-generator with a light load. There are here two effects—the dip in the curve and the swing of the ordinate between the dotted limits. The curve shows a very strong 3rd harmonic in phase with the generated wave, and nearly equal to it in amplitude, added to which is a 13th. To explain the origin of the third, it must be first noted that the curve is lagging with regard to the 'bus-bar voltage by an angle of 53 deg.—that is, 23 deg. with regard to the coil voltage—so that the magnetising current component is 0·37 of the whole. It is well known that hysteresis in iron distorts magnetising current waves by giving rise to harmonics, of which the 3rd is the most important. In the given curve the distortion is aided by the

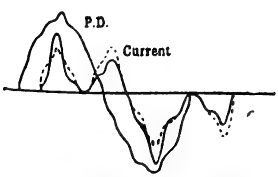
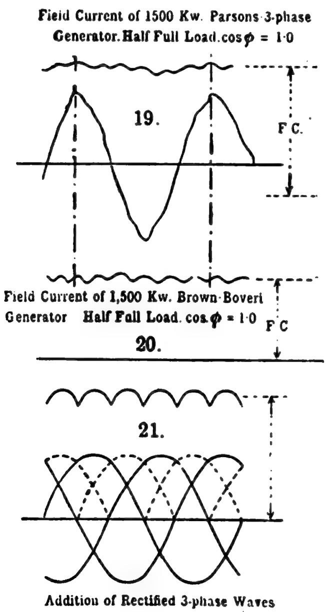


FIG. 18.—Effect of Lagging Current in Generator on Current Wave-form.

way in which the machines were connected. When generator windings are joined "three-wire star," no 3rd harmonic can exist; but when the neutrals of generator and motor are earthed, the ordinates of the 3rd harmonic in each phase are added, and a triple-frequency current flows in each winding and to earth. Moreover, the magnetising component of the current in a motor reacts in opposite phase to that in a generator with regard to the voltage. A 3rd harmonic of magnetisation in the motor is, therefore, in phase with one in the generator, and a triple-frequency current circulates through the machines. As the excitation was raised, the dip in the curve disappeared at about quarter full load, and the current became approximately sinusoidal.

§ 5. Periodic Variation of Exciting Current in Three-Phase Machines.

The reaction of a large demagnetising component upon the field circuit must in the above case have been very marked. Unfortunately, no record of this was taken at the time, but some fifteen months later I obtained Fig. 19, which is the exciting current of the same machine with a load of 160 amperes. There are here six well-defined waves per period superposed on the continuous exciting current. These arise from the double-frequency magnetising effect of the current in each phase in turn. The existence of these three-phase field disturbances has been disputed, but that they probably exist in all machines, and do not depend upon a particular design, is seen by their being equally pronounced in the Brown-Boveri generator (Fig. 20).



FIGS. 19 TO 21.—Effect of Armature Reaction on Exciting Current of Three-phase Generator on Load.

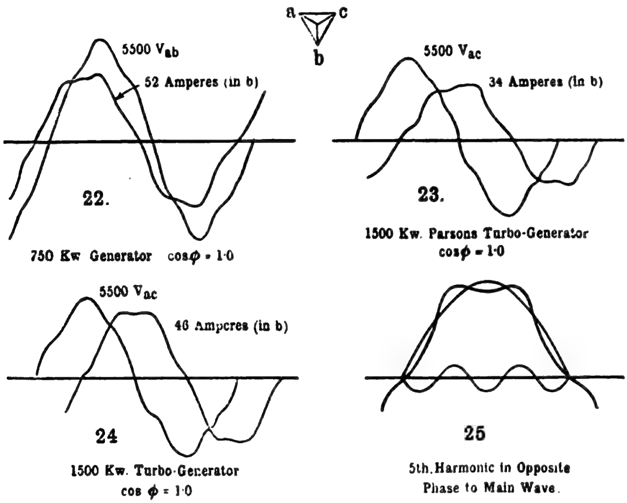
The calculation by which the back ampere-turns of armature reaction are found in theory to be perfectly steady, assumes that "the effect of a constant current in the armature coils varies as a sine curve when their position is reckoned from the centre of a pole." The influence of the breadth-coefficient of the winding is also neglected. That these assumptions are only approximate, which is all they are said to be, and do not represent the true facts, is here shown to be the case. The diagram Fig. 21 may help to make the origin of these ripples clearer. The lower halves of the curves have been reversed to

show their action, irrespective of coil position. The positive and negative maxima lie under opposite poles, and the effect on the magnetic circuit is cumulative. Note the correspondence between the general shape of this ripple and that of the actual current, and that the former is most marked in the Brown-Boveri machine. On open circuit the field current is practically straight.

The origin of the curious rise in the voltage across the fields of certain large three-phase generators is here evident, and the lower the initial flux-density in the magnet cores the greater the rise will be.

§ 6. Power Factor of Large Generators on a Water Load.

There has been some discussion recently upon the fairness of testing large alternating-current generators on a water load on account



Figs. 22 to 25.—Wave-forms and Power-factors of Three-phase Generators on Water Load.

of the lead said to be produced by the capacity effect of the electrolyte. The following curves (Figs. 22, 23, 24) may therefore be of interest. By careful measurement of Fig. 22 it is found that the angle between voltage and current on the paper is 28½ deg., but this is caused by the presence of a harmonic, which has the effect of bringing the curves nearer on the zero line. Taking the equivalent sine wave, the angle is exactly 30 deg. Again, with the Parsons turbine, the angle is 90 deg. at 34 and at 46 amperes. The possible error in these measurements—due to the oscillograph cam—is about 3 deg. Since the cosine of 87 deg. is 0·998, the power factor of large generators on a water load may, therefore, be taken as unity, with a possible error either way of one-fifth per cent.

The tops of the current waves are in all three cases flattened. This has nothing to do with the liquid resistance, but is caused by the 5th

harmonic having changed its phase by 180 deg., as may be seen by comparing Fig. 25 with Fig. 1. In the generator wave this harmonic was nearly in phase with the fundamental; now it is opposite to it at at the start of the period. As a generator the machine was connected "four-wire star"—*i.e.*, with neutral point earthed—but now the water resistance forms a mesh across the line wires, and the earth connection on the generator is removed. It can be shown that the phase position of an n-th harmonic changes when the connections are changed from four-wire star to mesh, either by 180 deg. or not at all; in this case by 180 deg. But why should the Parsons machine, which has apparently only higher harmonics than the 5th, show the latter in the current? The answer is, I believe, to be found in the field ripples of the preceding section. There are six of them to a period, produced by armature reaction, and their further reaction upon the armature current is brought out in a striking manner by this shift of phase due to mesh connection. The distortion of the current wave observed in Curve 22 is the result of having only one slot per pole per phase. It is similar to the sweeping forward of the magnetism in continuous-current generators, and with the two slots of the Parsons machine is less marked.

§ 7. Phase Swinging.

The influence of unequal turning moment in generators is a subject which in this section at least is somewhat stale. There is, however, an

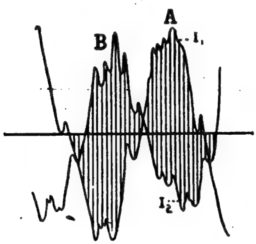


Fig. 26.—For Corresponding Voltage Wave-form, see Fig. 6 in Phase with A $\cos\phi = \cdot 95$.

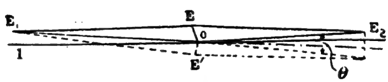


Fig. 27.—Generator Voltage Steady. Motor swinging through Angle θ.

interest attaching to the following curves on account of the reversal of current. Fig. 26 was taken at Manors, when two 500-k.w. motor-generators were running light in parallel, but with no direct-current load, from a single generator at Neptune Bank driven by a marine-type triple-expansion engine. The corresponding wave-form of the generator is Fig. 1 above. The voltage shows 5th and 13th harmonics, and was practically steady except for the small sliding movement of the ripples. The current wave presented the most remarkable appearance. It seemed a living thing, swinging as it did from one position (A) to the other (B) at 100 times a minute, the tops of the waves shooting out like tentacles. It is a very suggestive example of phase-swinging,

the more so because there is little sign of a lateral movement. The curves collapsed on themselves and sprang out in the reverse direction. To explain this, let OE_1, OE_2 (Fig. 27) represent the voltage vectors of a generator and synchronous motor respectively, running light with a power-factor nearly unity. The resultant voltage, OE, is therefore small. If now, by reason of the unsteadiness of the engine speed, the vector OE_1 is set swinging, the motor vector will follow, and if the disturbance is great, may swing past the zero line. As it approaches opposition to OE_1, OE falls to zero, and increases to some opposite maximum OE^1 at the end of the swing. The steady position of OE_2 is usually above the zero line; the value OE^1 will therefore be less than OE. The current in the circuit is proportional to OE, and by inspection of the curves we see it diminish from a maximum I_1, pass through zero, and increase to a lesser maximum, I_2. By measurement of Fig. 26 it is found that the relative angle of swing was six times the steady phase displacement between motor and generator; its absolute value cannot be determined from the curves. The power-factor of the circuit was 0·95. In the lower position (B) the 11th harmonic is prominent, and in the upper there is added to it—conspicuous at the maxima—a smaller 23rd or 25th.

§ 8. Direct Observation of Phase Displacement with Load.

There is one more effect to which I wish briefly to refer. The measurement of the steady phase displacement between, say, two alternators in parallel, or a synchronous motor and its generator, depending upon excitation and load, has not hitherto been experimentally possible, though the general effect is well enough known. If a small white patch is placed on the side of one of the revolving poles of a synchronous motor, and this is illuminated by an arc alternating at the frequency of the circuit, the effect is a curved white line, but if it is observed through a fine slit cut in the edge of a disc driven by a small synchronous motor the patch appears stationary. On raising the excitation of the motor, it moves forwards to a new position, and backwards if it is lowered, the amount of phase displacement corresponding to a change in either of the vectors OE_1 or OE_2. The great advantage of this new method is that it gives the actual movement of the rotor, and the influence of armature reaction in alternators in lowering the *generated* voltage can now be observed. For OE_1 and OE_2 are not the terminal but the generated volts in the respective machines, and there is no phase displacement unless these change.

For the direct observance of phase-swinging the method is very useful. When load is thrown on or off a motor or generator, the rotor appears to make torsional oscillations on the shaft, usually dying out in about half a minute. The time of oscillation at different excitations can be found, and the risk of hunting on any particular circuit determined. The fluctuation of current, and therefore of torque, by the variation of generator speed can also be readily seen. The arrangement is, in effect, an optical tachometer, and by the use of an enclosed

revolving drum on which sensitised paper is mounted, continuous photographic records could be obtained.

Mr. Ralph.

Mr. G. RALPH: There is one point I should like to mention with reference to testing alternating-current generators on water load. I once had a curious experience in testing a 200 k.w. single-phase high-voltage machine. The resistances were placed in two water-tubs in series, and it so happened that it was easy to put an ammeter between them as well as at the machine. The one between the resistances always read less than the machine ammeter even when they were interchanged. I should like to know whether capacity can possibly account for the large difference observed.

Mr. Stoney.

Mr. GERALD STONEY: This interesting paper enables one to see something of what goes on inside electric machines. As to the wave-form of the Parsons Alternator being so much smoother than that of the Brown Boveri machine, there are differences in design. One difference which may be the cause of the ripples is that the first machine has closed slots, the other open slots of large size. I think open slots are more liable to cause ripples than closed ones. Another view of the matter is that the ordinary magnet winding of the Parsons machine is very much better than the flat surface winding of the Brown Boveri type. I doubt whether short air-gaps have a very large effect. Then, again, high saturation of the pole-tips is of great importance, and this condition is found in the Parsons, but the saturation is low in the Brown Boveri machine. I consider Fig. 18 very interesting. There is more to be done in the way of improving the alternating-current system by improving the power-factor than by any other method. Dr. Thornton mentions the ripples caused by armature reaction. We have had experience with them on single-phase machines at Hastings. Some machines showed a considerable rise in the resistance of the field circuit as the load was increased, and this was probably connected with this effect. The small ripples did not seem to do much harm.

Mr. Law.

Mr. A. H. LAW: I should like to ask Dr. Thornton a question regarding a paragraph of the paper where it appears that a small variation in the exciter is accompanied by some variation in the shape of the E.M.F. wave. With a periodicity of 300 I should hardly have thought that this would have any effect on the large masses of iron in the magnet body. Amplifying what Mr. Stoney said about resistance in the field rising as load came on, on short circuit the effect is magnified. The apparent resistance is 2½ times the ohmic resistance, which figure I know to have been reached on a large two-phase plant. Is it possible that the actual field current flowing on short circuit is something the same shape as Figs. 19 and 20, with ripples very much deeper? I do not know whether this is possible, but if so it would presumably cause heating of the magnet on short circuit.

Mr. Clothier.

Mr. H. W. CLOTHIER: I am afraid I am not very fully informed on the subject, but I should like to say that it seems to me that the information we have before us is taken from curves obtained under ordinary conditions. I should like Dr. Thornton to tell us whether he has had results taken under abnormal conditions.

Mr. F. O. HUNT: I should like to ask Dr. Thornton with regard to the water tests, whether there was any possibility of error owing to the testing tank not being sufficiently insulated. Mr. Hunt.

Mr. C. TURNBULL: The question arises how to get over these new difficulties in connection with alternating currents. My friend seems to think that the only way is to use Parsons Turbos and Parsons Generators. Another question is as to the effect of small variations in current in large masses of iron. Assuming that it is required to get a machine to respond to sudden change in the magnetic circuit, is it better to use laminated or solid poles; or, to put it otherwise, would a transmitted wave tend to be smoother with solid or with laminated poles? Mr. Turnbull.

Dr. THORNTON (*in reply*): The effect mentioned by Mr. Ralph is most likely caused by leakage, one pole of the machine being earthed; capacity cannot account for so large a difference. Mr. Hunt's question is on the same point, but there can be no direct leakage to earth from the tank. The earth connection to the centre of the star winding of the generators is removed when the machines are on the water load. In reply to Mr. Stoney, the difference in the wave-form of the machines is no doubt due to the slots. In the Brown Boveri machine the slots are simply rectangular. With regard to armature reaction, I might mention some experiments by Banti on the power-factor of a continuous current delivered by a single-phase rotary converter. It was there about 0·84, and lower values have since been obtained. That is entirely due to armature reaction superposing an alternating current upon the continuous output. Mr. Law's question I think should be the other way about. It is a fact as shown by Figs. 19 and 20, that the effect of armature reaction gets through the solid mass of the magnet into the exciter circuit. For the apparent resistance of this circuit to rise $2\frac{1}{2}$ times, the R.M.S. alternating-current ampere-turns of armature reaction applied to the magnetic circuit must have been more than twice as great as the ordinary continuous-current ampere-turns. The result of adding an alternating current of I_1 amperes to a circuit carrying a direct current of I_0 amperes is to give an ammeter reading of Dr. Thornton.

$$\sqrt{I_0^2 + I_1^2}$$

so that if

$$\frac{\sqrt{I_0^2 + I_1^2}}{I_0} = 2{\cdot}5$$

$$I_1 = 2{\cdot}25\ I_0,$$

a result which shows the tremendous effect of armature reaction in a machine on short circuit. It would be interesting to try the same on a three-phase generator or converter. There is no doubt that the field ripple would then be very much greater than in Fig. 19. With regard to Mr. Clothier's question, I have no experience of abnormal effects; and as to using the oscillograph under such conditions, I do not think one would be permitted to attempt it on a large scale. Mr. Turnbull raises a point which would repay investigation. Personally I

Dr. Thornton.

think that a laminated core would prevent rapid changes in an ordinary exciting current more readily than a solid one. In the latter case a current suddenly switched on rises at first more rapidly than in the former, but afterwards more slowly. In regard to alternating wave-forms the case is rather different. The small ripples arising from the teeth do not get through the magnet core at all. In an alternator, they are almost localised in the pole-face, teeth, and the iron just below the teeth. The armature reaction does, and is opposed by the eddy currents in the solid cores. In this case there will certainly be less amplitude of *total* magnetic movement when the cores are solid than when laminated on account of the time required for the changes to take place and there will be, therefore, less disturbance of the generated wave-form of the machine.

MANCHESTER LOCAL SECTION.

MECHANICAL CONSTRUCTION OF STEAM TURBINES AND TURBO-GENERATORS.

By W. J. A. LONDON, Associate.

(*Paper read February 28th*, 1905.)

The design of reciprocating steam engines can now be safely said to have reached a stage of more or less standardisation. The proportions of the various details to give the best results under given working conditions can be found in any standard work on the subject. This standardisation can be accounted for, not only by the number of years which the reciprocating engine has been a standard article of manufacture, but perhaps more from the fact that the reciprocating steam engine, as an engine, is not patented, and consequently designers from all parts of the world have been devoting their energies to arrive at the solution of "best practice." Had the development of this class of machinery, however, been in the hands of one man or one firm only, no matter how clever they might have been, it is too much to expect that they could have attained the same degree of perfection that now exists.

Designers differ largely in their views, and it is only by the failures and successes of the schemes of these various engineers that we have been able to deduce standard formulæ for the proportions of the respective parts of steam engines.

In comparison with the above, then, let us consider the condition of affairs with the steam turbine. About twenty years ago the Hon. C. A. Parsons, followed shortly by Dr. Gustav de Laval, conceived the idea that a practical and commercial steam engine could be manufactured on the simple turbine principle, and having demonstrated the possibilities of such machines, they went to work to develop the turbines we now know so well. These engineers, being convinced of success in their own minds, very naturally applied for and obtained patents covering as many principles and details as was possible. This monopoly of patents, no doubt, to a certain extent has prevented the development of the steam turbine in other sources, but had no such patents existed, judging by the prejudice and scepticism that has existed in the minds of engineers that steam turbines would never take any sort of prominence in the engineering world, it is very doubtful if,

up to the last few years, many engineers would have had enough confidence to have put their money into the development of the steam turbine. It is only during the last five years that any prospect of competition has shown itself, and in England two and a half years ago Messrs. Parsons (with the exception of Messrs. Greenwood and Batley, who have confined themselves to small machines only) were the only manufacturers of steam turbines in the country.

Too much credit cannot be given to the Hon. C. A. Parsons and his staff for their untiring energy in bringing the steam turbine to its present prominent position. Efficiency, maintenance, and durability tests have been carried out by independent experts, which clearly prove that the modern steam turbine as regards general efficiency can hold its own with any form of the best reciprocating engine.

As pointed out in connection with reciprocating engines, the effect of competition is often responsible for considerable modification in designs. With all due respect to the Hon. C. A. Parsons for the success he has attained, it is not too much to expect that now the field of steam turbine manufacture is being so greatly enlarged considerable development will take place during the next few years in the general design and construction of this type of engine, nor is it too much to say that there is still a great deal to learn. It is only by the experience of engineers with different ideas that we shall finally arrive at the same standardisation that now exists in high speed, marine, and low speed engine practice.

The same remarks hold good for turbo-generators. Messrs. Parsons, who build their own, had had up to about four years ago the monopoly of the experience in Europe in their design. The Westinghouse Companies, however, in America, have during the last six or seven years done some very successful work in turbo-electric machinery.

This field is now being considerably widened, and designs are consequently undergoing considerable modification.

The design and successful operation of steam turbines has opened up a wide field for research. Difficulties crop up in the mechanical construction of steam turbines and their generators unknown in any other field of engineering, and those having experience in this branch of the profession have, up to the present, been very reluctant to publish their difficulties or let the world profit by their experience.

In view of the above, the object of the present paper is to briefly deal with some of the difficulties met with in the successful design of steam turbine machinery, hoping that advantage may be gained by the opening of a discussion on this important subject. The steam turbine has during the last two or three years come into such prominence, threatening as it does revolution in the steam engine world, that engineers and scientists have realised the importance of fathoming and understanding as much as possible about the various laws governing its action. In consequence, numerous treatises have been published by some of the world's ablest professors on the theory and action of steam in the steam turbine, and on other theoretical considerations connected with their design. Amongst these, special reference should be made to

Dr. Stodola's "Dampfturbinen,"* and the papers before the American Society of Mechanical Engineers by the late Dr. Thurston † and Mr. F. Hodgkinson. ‡ These treatises, dealing as they do with the higher theoretical problems, contain much essential information to the designer of steam turbines, but they do not mention the mechanical difficulties met with in the design and successful operation of these machines. Papers innumerable have also been read during the last few years before Engineering Societies, but these can also be said to lack practical information. It is an old saying that "an ounce of practice is worth a pound of theory," and this saying was never more true than when applied to the case under consideration; and those engineers who have had experience in the design, construction, and operation of turbines know the importance of giving attention to what might be called the untheoretical points.

The early types of steam turbines ran at enormously high speeds of revolution, and Messrs. Parsons and De Laval appreciated the fact that special construction of the shaft, bearings, etc., was necessary to ensure smooth running under these conditions. De Laval devised the well-known flexible shaft, which design to this day is doing good work. Mr. Parsons, on the other hand, conducted experiments with shafts running up to a speed of 40,000 r.p.m., and arrived at a somewhat similar solution to De Laval, with the exception that the bearings were made flexible to follow the whipping of the shaft.

Mr. Parsons's idea, when introducing his turbine, was that it formed an ideal prime mover for electric generators owing to its high speed and even turning moment. The first turbo-dynamo built by Mr. Parsons in 1884 was the outcome of very careful designing, and proved very satisfactory. Experience with larger units, however, has shown that in a great many cases the generator itself has been the greatest cause of trouble. It is not too much to say that the prejudice that has existed against turbo-electric generators has to a great measure hindered the progress of the steam turbine. In the design of these high-speed generators we also find the small details of mechanical construction playing a vital part.

Steam turbines are now constructed with vertical and horizontal shafts, and a comparison of the advantages and disadvantages of these respective types is interesting when studying turbo-generator design from a general engineering standpoint. The vertical turbine naturally appeals to the engineer at first sight as being the most suitable for high speed, there being no sagging in the shafts (due to its own weight between the bearings). The further claim is made for the vertical engine that it takes up less floor space than does the horizontal design, this saving meaning a lower cost of foundations and smaller engine room. The present designs of the vertical turbine, however, now on the market do not differ to any great extent in superficial floor area from that taken by one or two types of horizontal

* The English translation of this work by Dr. Louis C. Loewenstein is now in print (A. Constable and Co., Haymarket, S.W.).

† *Trans. Amer. Soc. Mech. Engineers*, No. 876, vol. xii. p. 170.

‡ *Ibid.*, vol. xxv. (Chicago Congress, 1904).

machines. Against the advantages set forth above of the vertical machine we must put the following disadvantages: General inaccessibility, and the difficulty met with and time necessary for the withdrawing of, say, the turbine spindle to attend to any repairs that may be necessary. The footstep bearing necessary to support such a rapidly revolving heavy shaft calls for an exceptional design, and though we understand all difficulties have now been successfully met in a practical way, yet the fact remains that its fallibility means the failure of the turbine. The design of a footstep bearing for such work as water turbines where very low rotative speeds are adopted is a very different thing from the design of a bearing for the speeds necessary in steam turbine practice, and should the supporting fluid give out considerably more damage would be done than in the case of a similar accident to a water turbine. Auxiliary machinery is necessary for the supply of this supporting fluid, and also a relay connected to an emergency pump should an accident happen to the first one. This auxiliary machinery all means additional plant to look after, and also necessitates floor space which must be added to that taken up by the turbine. A further disadvantage of the vertical type compared with the horizontal is the fact that the heat radiated from the turbine cylinder rises up and heats the generator. The top bearing must be so designed that it is not possible for any oil to leak, which would immediately drop on to the generator, the effect of this being often very serious.

The stuffing box between the turbine and the generator must also be absolutely steam-tight to prevent the possibility of any vapour rising into the generator. These points all necessitate very careful designing, and in the event of their failing to perform their respective functions, serious troubles are likely to result. None of the above difficulties are met with when the machine is built on a horizontal axis. Summarising the above we get the following advantages of the two types of machine:—

Horizontal.

1. More accessible.
2. The whole plant being on the floor can be easily examined, and turbine and generator can each be separately dismantled without disturbing the other.
3. No footstep bearing, and less auxiliary machinery in consequence.
4. Heat radiated from turbine does not affect the generator.
5. No risk of oil from bearings leaking into generator.
6. Any steam leakage from the stuffing boxes does not enter the generator.

Vertical.

1. No sagging of shafts.
2. Smaller floor space (?)
   (*a*) Smaller engine room.
   (*b*) Cost of foundations.

It is often put forward that steam turbines require little provision in the way of foundations, and that the machine can be placed on the floor, provided such floor be strong enough to take the dead weight, and work perfectly satisfactorily. This is quite true, but at the same time trouble sometimes arises because the foundations, though amply strong, are not suitable for that class of machinery. Where the foundations are at all elastic, vibrations will be sometimes set up in them causing a certain amount of inconvenience to inmates of private houses or hotels where turbines are installed. The spindle being slightly out of balance may set up vibrations in the turbine itself and be transmitted through the bedplate to the foundations. These vibrations can, however, if not too severe, be damped out in the majority of cases by insulating the bedplate of the machine from the floor by a layer of wood, felt, or lead, or by a combination of all three. It is usual in small installations to provide this form of damper in the foundations, as it is rarely possible to eliminate all vibrations in the machine itself. It sometimes happens, however, that when the vibrations are thus stamped out entirely in the vicinity of the machine, they can be felt in some structural steel work some distance away. It is then most probably due to some harmonic action, and can be generally eliminated by slightly altering the speed of the machine or interrupting the wave of vibration in the girder or other structure that is giving the trouble.

In a recent installation the writer has been connected with, two machines ran in parallel at the same speed, each machine apparently ran perfectly smoothly, but in another part of the building serious vibrations were experienced. This was entirely eliminated by slightly altering the speed of one of them.

For large machines of, say, 1,000 k.w. and upwards running at speeds of 1,500 r.p.m. and under it has been found possible to balance the rotating elements much more accurately, and in consequence of the little vibration that is likely to arise it is preferable to build the bedplate right into the foundations; for large machines this undoubtedly makes the better arrangement.

Foundations, where possible, should be of some moderately unelastic body, such as concrete, or brick and cement, and should extend the whole length of the turbine bedplate. This form of foundation, shown in Fig. 1, gives good results, and in many cases is the best form for such work. All condensers and auxiliary apparatus can be placed under the turbine, and every part of the plant is easily accessible. Steel or iron constructions in foundations are not to be recommended as they invite the trouble mentioned above in connection with the smaller machines.

The general principles governing the action of modern steam turbines are well known. The design and construction, however, apart from the actual design of the nozzles, blading, etc., are so greatly affected by the governing principles that the writer has not thought it out of place to briefly run over these here. They may be divided into two classes :—

(1) Pure impulse or action (simple and compound).

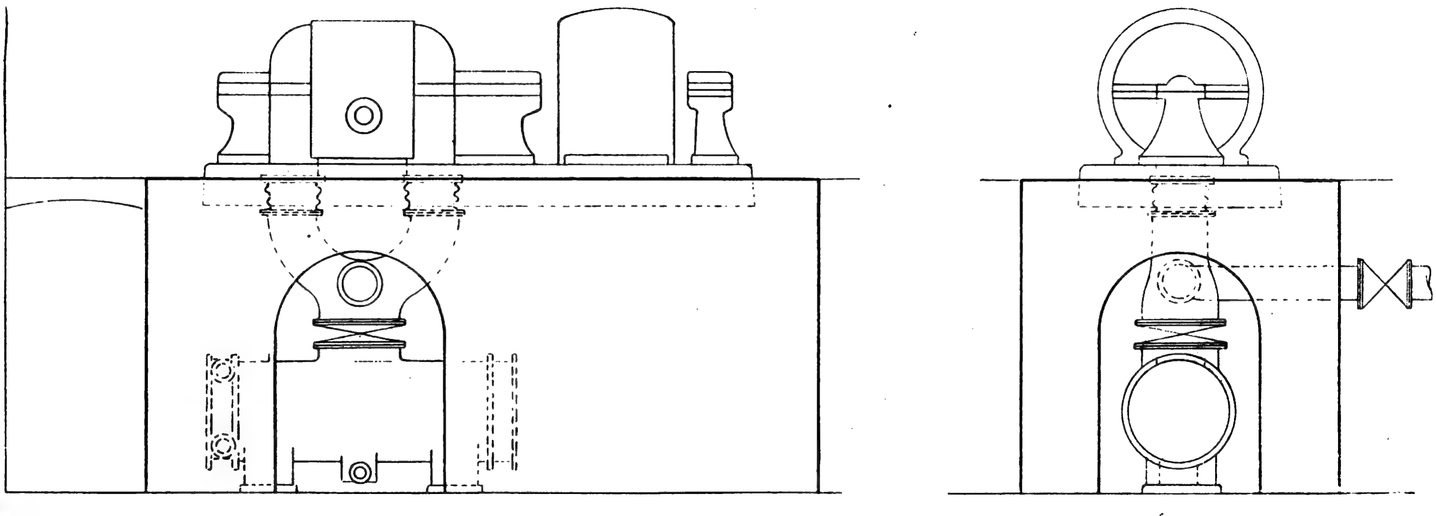


FIG. 1.

Examples :

Simple. De Laval and early form of Stumpf.

Compound. Rateau, Zoelly, Hamilton Halzworth, later Stumpf and Curtis.

(2) Combined action and reaction turbines.

Examples :

Parsons and Westinghouse.

In Class 1, the whole of the expansion of the steam takes place in the nozzles or stationary elements, the velocity resulting therefrom being absorbed in the rotating wheels in the form of kinetic energy.

In the De Laval the whole of the expansion takes place at one time, the steam being expanded right down to condenser or atmospheric pressure in the one set of nozzles. The velocity obtained is enormous, and consequently high peripheral velocities are necessary in the rotating wheel. In the compound impulse type the expansion takes place in two or more stages of the stationary elements, but no expansion is supposed to take place in the rotating buckets, so that there is no difference of pressure on the two sides of the rotating wheel; this point is important.

In Class 2, expansion takes place in the revolving wheels as well as in the stationary elements, so that a difference of pressure exists between the two sides of the rotating buckets; this pressure must be balanced, and further, there is a tendency for the steam to leak across the top of the rotating blades, which does not exist in the action type; this point is of great importance in the consideration of the design of the Parsons and Westinghouse turbines.

Returning to the first type, namely, the simple De Laval turbine, this is one of the earliest practical types of steam turbine, and the general design is interesting from the fact that it has undergone little modification since its origin, and it cannot be said that there is now much room for criticism and improvement. The fundamental principles of this turbine, as pointed out above, necessitate enormously high peripheral speeds to attain anything like reasonable efficiency.

For example :

Steam at an initial pressure of 160 lbs. per square inch expanding in a nozzle to a vacuum of 28″, the velocity of efflux (Vs) will be 4,034 ft. per second.

It is well known that the velocity of the buckets (Vw) in an action turbine should, for maximum efficiency, be about one half the steam velocity (to be more correct 47 %),* so that with the conditions given above and the angle of the nozzle relative to the plane of rotation 20° we get

$$V_w = \cdot 47 V_s \cos 20$$
$$= 1{,}781 \text{ feet per second.}$$

In practice, however, this speed is much in excess of that actually

* *Trans. Inst. of Engineers and Shipbuilders in Scotland* (vol. xlvi., part 1), "Steam Turbines, with special reference to the De Laval Turbine," by Konrad Andersson.

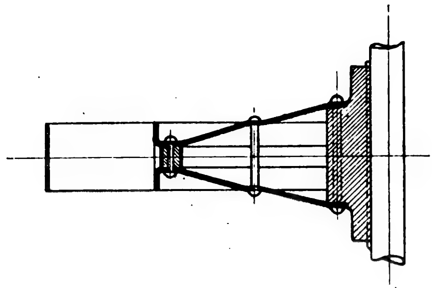


FIG. 6.

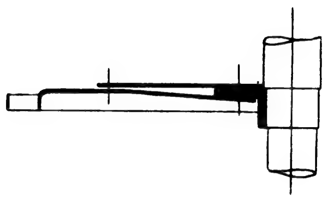


FIG 5

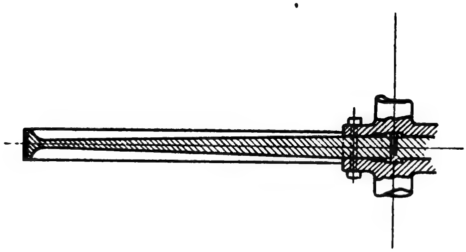


FIG. 3.

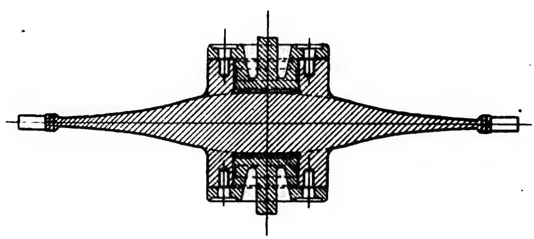


FIG. 2.

obtained, the maximum peripheral velocity being about 1,378 feet per second. This is about 77·3% of the theoretical, whereas in the smaller machines this comes down to 28·9%. The bucket wheel of a De Laval turbine is shown in Fig. 2.

The following table gives the actual peripheral velocities of Laval turbines of different sizes:—

Size of Turbine.	Middle Diameter of Wheel.	Revolutions per minute.	Periph. Speed, ft. per second.	R.P.M. of Generator.
5 H.P.	100 mm. 4 in.	30,000	515	3,000
15 „	150 „ 6 „	24,000	617	2,400
30 „	125 „ 8⅞ „	20,000	774	2,000
50 „	300 „ 11¾ „	16,400	846	1,500
100 „	500 „ 19¾ „	13,000	1,115	1,250
300 „	760 „ 30 „	10,600	1,378	775

Messrs. Lea and Meden, in their paper before the Chicago Congress last year on the De Laval turbine,* point out that these speeds are not determined by the limit of centrifugal stresses allowable. To quote from the paper: "Contrary to popular belief, there are no reasons either theoretically or practical to prevent the building of a safe turbine wheel with a peripheral velocity as high as 2,100 ft. per second; only economic reasons have put a limit to it."

The exact form of wheel for such a turbine has been the subject of considerable controversy during the last year or so, and the theory of the stresses in such a disc has been most exhaustively dealt with in connection with the other theories of the steam turbine.† It is still doubtful, however, whether the distribution of stresses in such a disc are thoroughly understood, and further, whether the formulæ accepted by engineers as correct are reliable.

The makers of the De Laval turbine so far have not seen their way to increase the diameter of their rotating discs, and consequently reduce the speed of revolution sufficiently for the direct driving of generators or other power converters, and in consequence gearing has always to be resorted to. This gearing is one of the most important points in the construction of the De Laval turbine; it is double helical, and in order to ensure smooth running with a velocity of 100 ft. per second on the pitch line, very careful machining of the teeth is necessary. The pinion and the wheel are now both made of steel, earlier types being made with a steel pinion and bronze wheel. Experience has shown, however, that the steel wheels are more serviceable. An important point in connection with the satisfactory running of this gearing is the correct method of lubrication. It would appear that to let the gear run in a bath of oil would serve the best purpose,

* *Trans. Amer. Soc. Mech. Engineers*, vol. xxv. (Chicago Congress, 1904).

† See "Die Dampfturbinen" by Dr. Stodola. Also "The Design of Steam Turbine Discs,' by Frank Foster, B.Sc.; the *Engineer*, Jan. 8, 1904. "Steam Turbine Discs," by Professor FitzGerald; the *Engineer*, May 13, 1904.

but this is not the case, as owing to the centrifugal force imparted to the particles of oil at the periphery of the wheels they fly off and do not sufficiently lubricate the faces. Lubrication, therefore, has to be resorted to by a small drip on to the working faces. The ratio of this gearing, as will be seen from the table given above, is about 10 to 1, so that the speed of the generators is comparatively moderate, and in consequence no special construction has to be resorted to in their case.

Exhaustive experiments and researches recently carried out by Professors Riedler and Stumpf have proved that wheels of a much larger diameter than those adopted by De Laval can be safely run, and in consequence they have built machines running with nearly the same peripheral velocity as his, but with so large a diameter as to give the low rate of revolution necessary for the direct driving of generators. For example :—A 1,500 H.P. Riedler-Stumpf turbine running at 3,000 r.p.m. has a wheel diameter of two meters (6 ft. 6¾ in.), giving a peripheral velocity of 1,030 ft. per second. A section of this wheel is shown in Fig. 3, and it will be seen that it differs slightly in its general form from that adopted by De Laval, further emphasising the point mentioned earlier in the paper as to the absolutely correct form for such a wheel.

The Rateau steam turbine consists of a series of discs mounted on one continuous shaft revolving between stationary diaphragms containing the distributors, which in reality are nozzles. This turbine is neither more nor less than a multiple De Laval. As already pointed out all the expansion takes place in the stationary element, so that there exists no difference of pressure between the two sides of the revolving wheel. This means that there is no great tendency for the steam to leak past the periphery of the wheel, and in consequence fine radial clearances between the wheel and casing are not needed. The earlier type of the Rateau turbine consisted of only one such cylinder. The machine in section is shown in Fig. 4. Here the peripheral velocity adopted is only about 300 ft. per second, so that to cope with the expansion from 160 lbs. to, say, 28 inches of vacuum the number of rows required, if the diameter is constant throughout, is 36. Owing to the great overall length of this machine as originally designed, it was found necessary to resort to a third bearing. This was placed in the centre of the cylinder midway between the other bearings, its object being to not only carry the weight but also to preserve sufficient rigidity in the shaft to ensure smooth running. It might here be mentioned that it is more difficult to obtain steady and smooth running in a long, springy shaft, at a comparatively low than at a high speed, especially when loaded with discs as in this case. This centre bearing is obviously wrong from a mechanical standpoint, and it was only to be expected that such troubles as heating of the bearings, lubrication, packing against leakages of steam or oil, difficulties of perfect alignment, etc., should present themselves. The later designs of this class of turbine consist of two separate cylinders, which undoubtedly make a much more satisfactory piece of machinery.

The spindle of each element consists of one throughgoing shaft

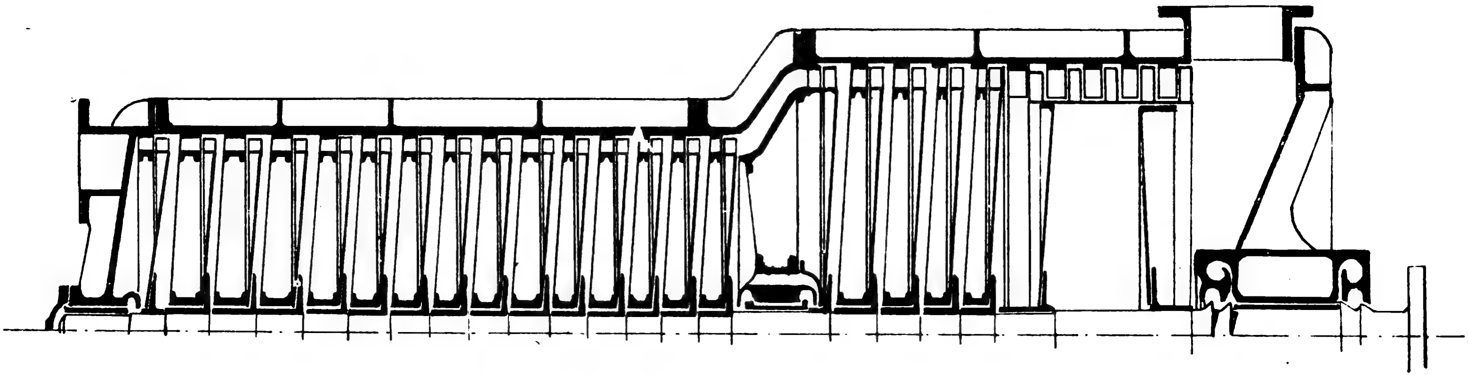


FIG. 4.

upon which is mounted a series of Z shaped forged steel discs, carrying the blades on their outer flange. The object of this construction is to allow the stationary discs to have as small an opening as possible at their centre to prevent leakage, as any leakage that may take place must pass round that part of the spindle which passes through the stationary diaphragms. There being no great tendency for leakage past the outside of the rotating member, small clearances here are not necessary, and in consequence any distortion that may take place in the outer shell, due to high temperatures, does not play an important part. Further, the tendency for distortion is less here than is the case in a Parsons turbine, the whole cylinder being stiffened by the internal stationary diaphragms. With a shaft of the construction given above, correct balance is of the greatest importance if vibration is to be eliminated. The diameter of the shaft, being comparatively small, offers little resistance to whipping. Further, the steel disked plates must in themselves be correctly balanced. The Z form of disc is not the best for high speed rotation, as owing to centrifugal force these plates must have a tendency to flatten out. Professor Rateau in his later designs has modified this construction of disc to that shown in Fig. 5, which is obviously more near the correct form for a high speed disc.

The Zoelly turbine is in principle identical with the Rateau, but the mechanical construction is somewhat different. The revolving discs of the Zoelly turbine are made of forged steel of a section similar to that used in the De Laval and Riedler-Stumpf turbines. With this construction Zoelly runs at a much higher peripheral velocity than Rateau, namely about 590 feet per second, so that the number of rows or discs is reduced from 36 to 10, and in consequence the shaft is much shorter. Even with fewer discs Zoelly divides the machine into two cylinders for the complete expansion, so that the distance between bearings in either cylinder is comparatively short, and the possible troubles due to whipping, as pointed out in connection with the Rateau, are greatly reduced. Stiff cast iron diaphragms are also used in the Zoelly turbine, so that the whole construction is about the best possible for that type of machine.

The Hamilton Holzworth is another example of this same type, the discs, however, carrying the blades are built up of plates similar to the later Rateau design, Fig. 6. This construction is lighter than the Zoelly, but its great number of parts do not make such a good mechanical construction as the Zoelly machine.

The Curtis turbine in general construction is very similar to the Zoelly; there is a slight difference, however, in its general principle, which has considerable effect upon its overall length. The Rateau and Zoelly turbines expand the steam in each stationary element, whereas in the Curtis, the expansion which has to be taken care of by two or more wheels, takes place in one expanding nozzle. This system has the effect of reducing the number of rotating blades necessary for a given expansion. This will be more clearly seen by the following :—

With a Curtis stage turbine with say, two wheels in each stage,

having a peripheral velocity the same as Rateau, namely, 300 feet per second, the velocity of the steam entering the first wheel must be such that it leaves the last row of each stage inert, then the velocity of the steam entering the last wheel is 640 feet per second, and at the first row it must therefore leave at 640 feet per second, so that the steam velocity on leaving the nozzles must be about 1,280 feet per second.* This corresponds to a drop in B.Th.U. per lb. of 37. Assuming the same total range of expansion as previously, giving a total available energy of 325 B.Th.U., this gives nine as the total number of stages and 18 the total number of rows of blades as against 36 in the Rateau,† so that by adopting a multiple wheel system at each expansion, the overall length is considerably shortened. This, of course, is due to the fact that the work done is proportional to the square of the velocity of the fluid.

The builders of the Curtis turbine consider that the vertical spindle is best suited to the requirements of this machine. The general advantages and disadvantages of the vertical spindle have already been dealt with. As this machine is very much shorter than the Rateau or Zoelly, it is the opinion of the writer that a turbine on the Curtis principle with a horizontal spindle would present less possibilities for trouble than with the vertical spindle. The vertical spindle requires balancing as in the horizontal to eliminate vibrations. The only advantage that the vertical can have is the elimination of sagging tendencies, and the possibility of using a somewhat lighter shaft. As recently pointed out, however, the machine is very short between the bearings so that it would appear that there is not much trouble to be anticipated on this score.

The design of the footstep bearing is an important detail, a sectional view of one form of which is shown in Fig. 7. As shown here it consists of cast iron bearing plates between which is pumped the supporting fluid. Oil is used with pressures up to 900 lbs. per sq. inch. Should an accident happen to the pump the plates at once come into contact and severe seizing takes place. Further, should the spindle drop to any extent a ledge is fitted just inside the vanes of one or more of the discs, which comes in contact with the stationary element, forming a most effective brake. In order to reduce the possibility of such an accident happening, an auxiliary pump is fitted which comes into action automatically should the first pump fail. This additional auxiliary machinery adds another complication to the whole plant. The writer understands that the design of the footstep bearing has recently undergone considerable modification, and that water is now used as the supporting fluid.

In the Parsons and Westinghouse turbines a totally different general construction to the impulse machines is called for.

As already pointed out, the principle of action in these turbines differs from the impulse machines by having expansion taking place in the revolving blades as well as in the stationary blades. This calls for

* These velocities are taken relative to the casing and plane of rotation.

† These are theoretical deductions, no losses being taken into account.

fine radial clearances. A construction of spindle such as that adopted by Rateau or Zoelly would not be sufficiently stiff to allow of small clearances round the periphery of the wheel; and further, balancing troubles would be greater than is the case with the present construction. With a drum type of spindle the loss by radial clearance space is somewhat larger than is the case with a disc type of machine, but skin friction is reduced to a minimum, there being no big areas revolving

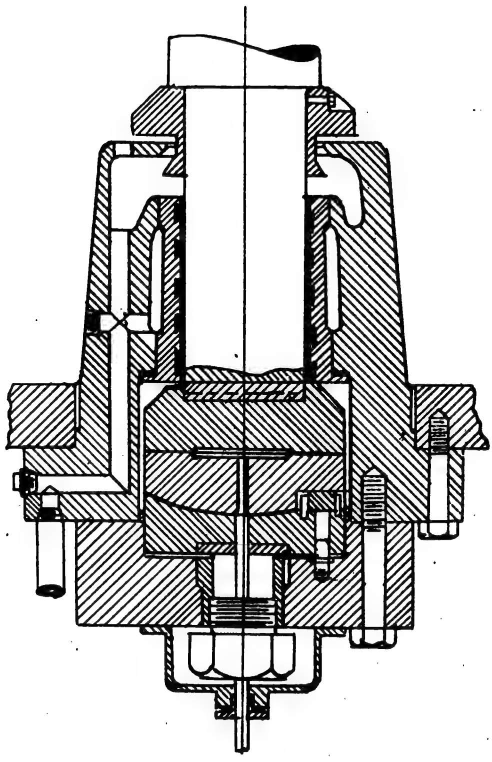


FIG. 7.

in media of different densities. A spindle of a Parsons' turbine is shown in Fig. 8B, and consists usually of a cast steel drum, having forged steel ends shrunk or pressed into it. This form of spindle is much stiffer than the construction with a throughgoing shaft with discs. A certain amount of whipping takes place, however, owing to its great overall length.

Turbines of 1,000 k.w. and upwards were, up to a few years ago, divided into two cylinders. This was mainly from a constructional point of view, as it was not known by the makers what would be the

resulting conditions from much larger diameters and lengths subjected to the varying pressures and temperatures peculiar to the turbine. Almost perfect circularity is essential throughout both cylinder and spindle, hence the reluctance to take the step in the dark. It has now been proved, however, that it is no longer necessary to resort to two cylinders; and machines up to 5,000 k.w. are now being constructed with a single cylinder.

In steam turbines of this type the steam passes through all the blades of the periphery, whereas with the Rateau, Zoelly, or Curtis machines, having no difference of pressure between the two sides of the rotating disc, the steam can be concentrated and passed through only a portion of the periphery. In consequence of the difference of pressure existing between the two sides of the rotating vanes in a Parsons' turbine, the whole annulus must be filled with steam, so that small diameters and low velocities have to be resorted to where its density is very high, in order that the percentage of clearance to blade height will not be excessive. As the steam expands, its volume increases, and as the number of rows of blades varies with the square of the velocity it is advantageous to step up in the diameter of the spindle as soon as possible. By doing so we get the awkward construction of spindle now in use. Various designs have been tried for these spindles, one type being shown in Fig. 8A, which consists of a plain forged steel drum having ends pressed into it of high carbon, or nickel steel. The steps are taken care of by a series of cast steel rings. This type of spindle has the advantage that the forged steel body in itself is more homogeneous than the casting, and consequently is less likely to cause balancing troubles. The cast steel rings can each be separately balanced and shrunk on. The disadvantage to this type being the number of parts necessary to make the whole, and the amount of machining and fitting necessary, which makes this construction more expensive than the first design referred to. Messrs. Parsons now use the type of spindle shown in Fig. 8B for all their designs, using cast steel for the drum. With spindles of this design, balancing troubles are often very serious, it being impossible to guarantee absolutely homogeneous material, and on account of the weakest section falling midway between the bearings whipping is likely to occur due to unbalanced mass.

The design of the stationary part of a Parsons' turbine is a very important item, this point becoming more evident as the machines increase in size, and in connection with marine turbines, the design of the stationary element has proved itself a very big problem. As the diameters increase, the greater is the tendency for distortion. Further, the cylinder cannot readily be supported between the bearings, owing to the fact that the centre part of the cylinder is at a higher temperature than the two ends, and the consequence would be that the cylinder would lift in the centre; this is exactly what must not take place. Further, any support or irregularity cast on to the part of the cylinder that must remain concentric at once causes distortion and makes the cylinder elliptical or otherwise out of truth. It is therefore

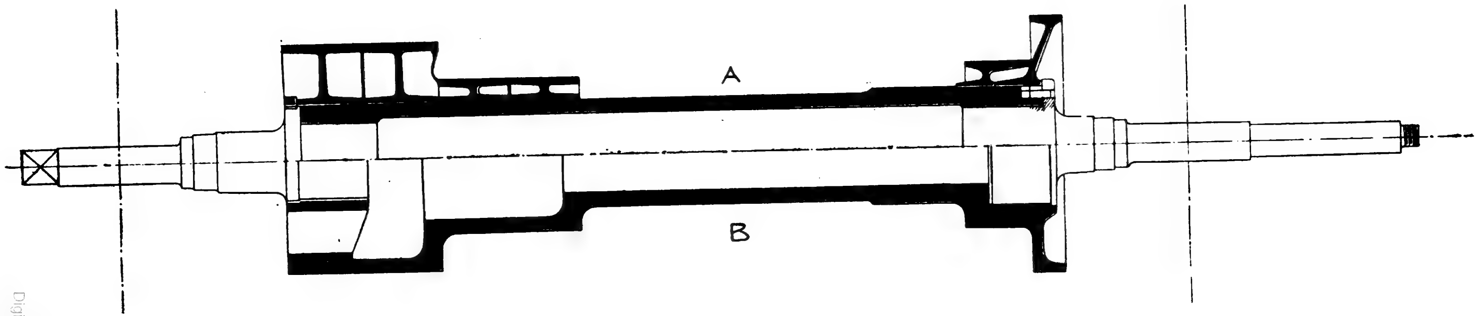


FIG. 8.

clear, then, that no rigid supports can be placed in the cylinder between the bearings. Further, any stiffening ribs or passages cast on to the cylinder have a distorting effect when the cylinder itself is subjected to high temperatures, the outer extremities of the rib then being at a lower temperature than the part adjacent to the cylinder proper. If ribs are necessary for stiffening of the under half they should be duplicated on the top half. A whole paper might be written on the subject of the design of such a cylinder, and the writer is confident that the majority of accidents due to blades fouling can be traced to the faulty design of this part of the turbine.

The British Westinghouse Company between two and three years ago, when entering the field of turbine manufacture, appreciated the difficulties that were to be anticipated in the design and construction of large turbine units, designed in line with any of the existing types of machines then on the market. After considerable study of the whole question the conclusion was arrived at that the most successful machine lay in the development of a turbine combining the principles already extensively used, namely, the principles of action and re-action. The objections to building turbines on the straight Parsons principle lay in the great overall length, mechanical difficulties in the construction of the spindle, and the adoption of dummy packing rings to eliminate end thrust. By making the turbine double flow, that is, by admitting steam in the centre and passing same through equal rows of blades on each side, end thrust and dummies were eliminated. In doing this it was appreciated that by taking care of the whole of the expansion on the Parsons principle the length of the machine overall would be much longer than a straight Parsons: further, the initial blade height would only be half the length of a single flow. This limiting blade height again would necessitate the stepping of the spindle, this point being explained when discussing the Parsons machine.

In expanding steam from 160 lbs. abs. to 28 ins. of vacuum the available work in heat units is 325 per lb., in expanding from 160 lbs. down to 60 lbs. abs. the available work is 78·9 B.Th.U., or about 24 per cent. of the total work in the whole expansion. In view of this it was considered that a slight amount of efficiency might be discarded in the H.P. end of the turbine if considerable mechanical improvements suggested themselves. By adopting a combined impulse wheel to take care of the expansion from boiler pressure to about 60 lbs. abs. it was found that the velocity necessary for the wheel fixed such a diameter that Parsons' blading could be successfully used on the one diameter already determined by the velocity of the impulse wheels. The specific volume of the steam at 60 lbs. pressure was so much increased from boiler pressure that the initial blade height on a large diameter was not prohibitive. The result of this combination is that a machine can be built which is very much shorter than the Parsons machine for given conditions, at the same time maintaining the same high degree of efficiency. With this type of machine skin friction of the discs of the ordinary impulse type of machine is eliminated. The

efficiency of the compound impulse section is comparatively high, but perhaps not so great as the remainder of the machine; this, again, is probably balanced by the losses due to skin friction in the long, high pressure end of the Parsons machine.

A longitudinal section of a British Westinghouse turbine is shown in Fig. 9, and the design as described allows of forged steel being used throughout in the construction of the rotating members. A centre shaft of high carbon steel extends from one bearing to the other, on which is shrunk the disc supporting the blade-carrying drum. The centre disc is of forged steel, and the outer drum is of weldless rolled steel. This outer drum carries the impulse blades in steel rings, which are shrunk on. The Parsons blading is carried directly in grooves in the main drum. Stiffening discs of thin steel are also fitted into the ends of the drum. A spindle of this construction is extremely stiff, and having a throughgoing shaft there are no joints in the spindle likely to give way and cause trouble. With rotating parts on the drum or hoop construction, the calculation of the stresses is simple compared to those relating to high speed discs of non-uniform shape. The stresses due to centrifugal force in a reasonably thin drum can be reduced mathematically to the following approximate equation:—

$$C = MV^2$$

Where C = Centrifugal force
M = Mass of material
V = Mean velocity in feet per second.

A still further simplification of this formula, which, when considering steel or other material of similar density, is near enough for rough calculations only:—

$$C_1 = \frac{V^2}{10}$$

C_1 in this case being the stress per sq. inch.

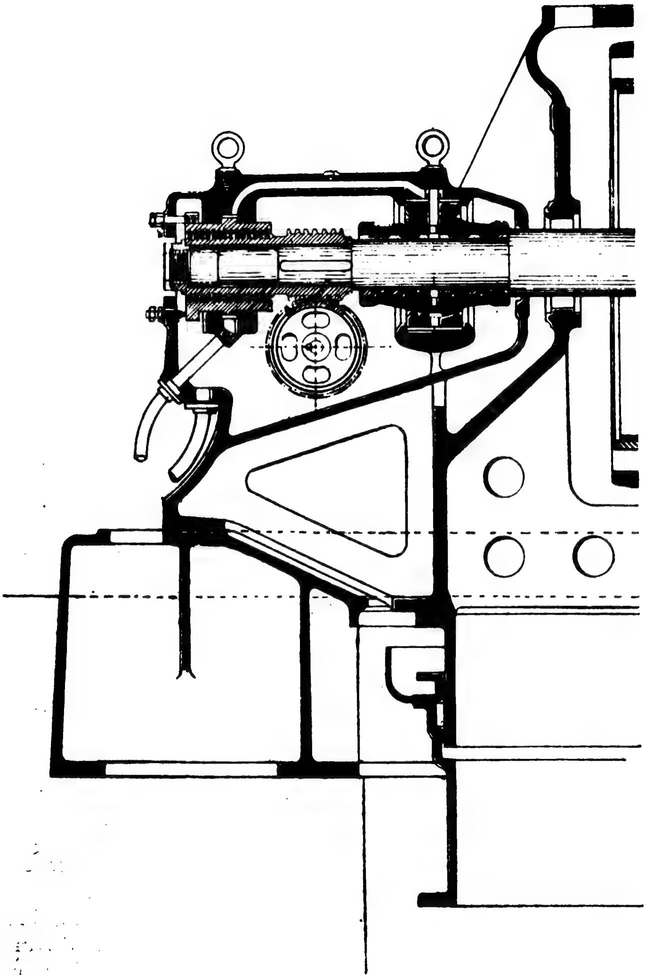
So that from the above the radius has no effect on the centrifugal stresses (other than loading by the blading), as in discs, and the peripheral velocity is therefore the limiting feature.

A chart is given in Fig. 10, from which may be seen the stresses in a hoop at different diameters and speeds.

The cylinder in the Westinghouse turbine is much shorter and is also stiffer than the ordinary Parsons type. Distortion is reduced to a minimum, so that blade fouling is an unlikely occurrence.

As mentioned earlier in the paper, the steam turbine on its introduction presented the greatest possibilities in the driving of electrical machinery. Special construction, however, of the generator was necessary to cope with the speeds demanded by this class of prime mover. The development of the turbo-generator since the original Parsons machine of 10 h.p. is interesting from the fact that the general design of a continuous-current turbo-generator of to-day has very little in common with the machine of 1884.

At the time of the introduction of the turbo-dynamo, and for several



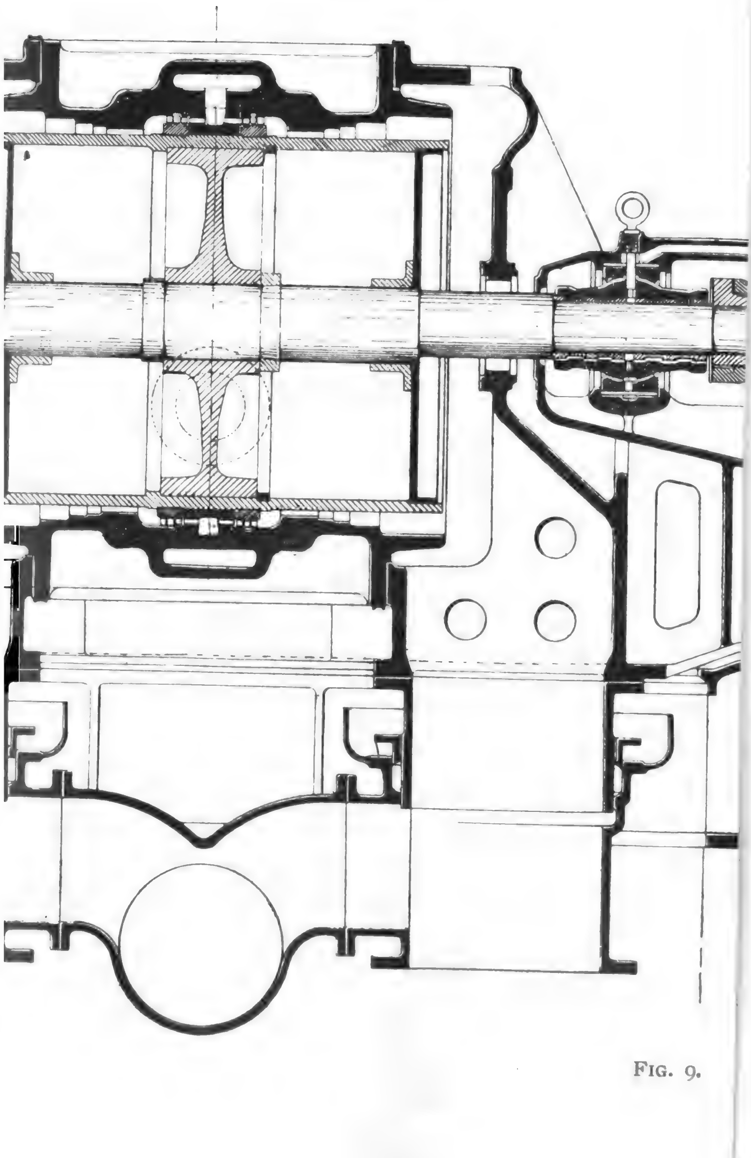


FIG. 9.

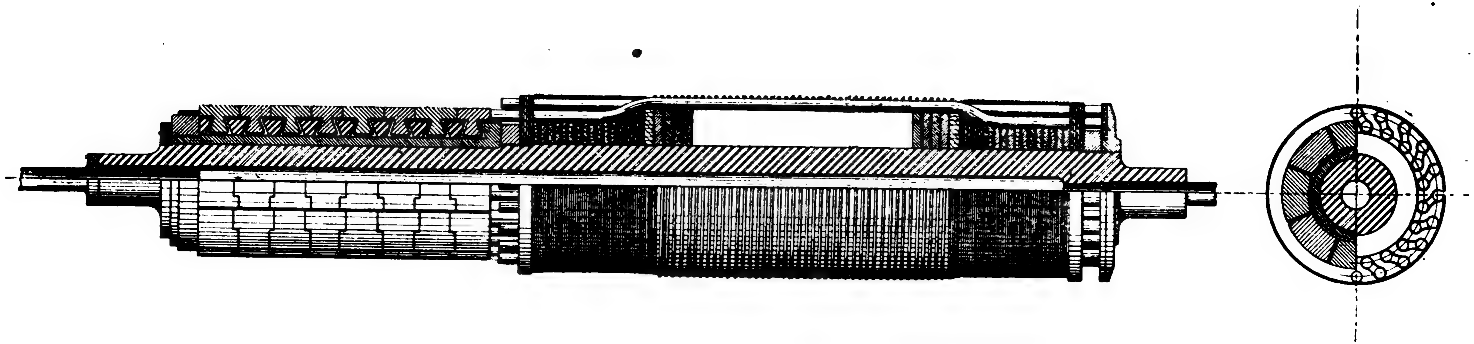


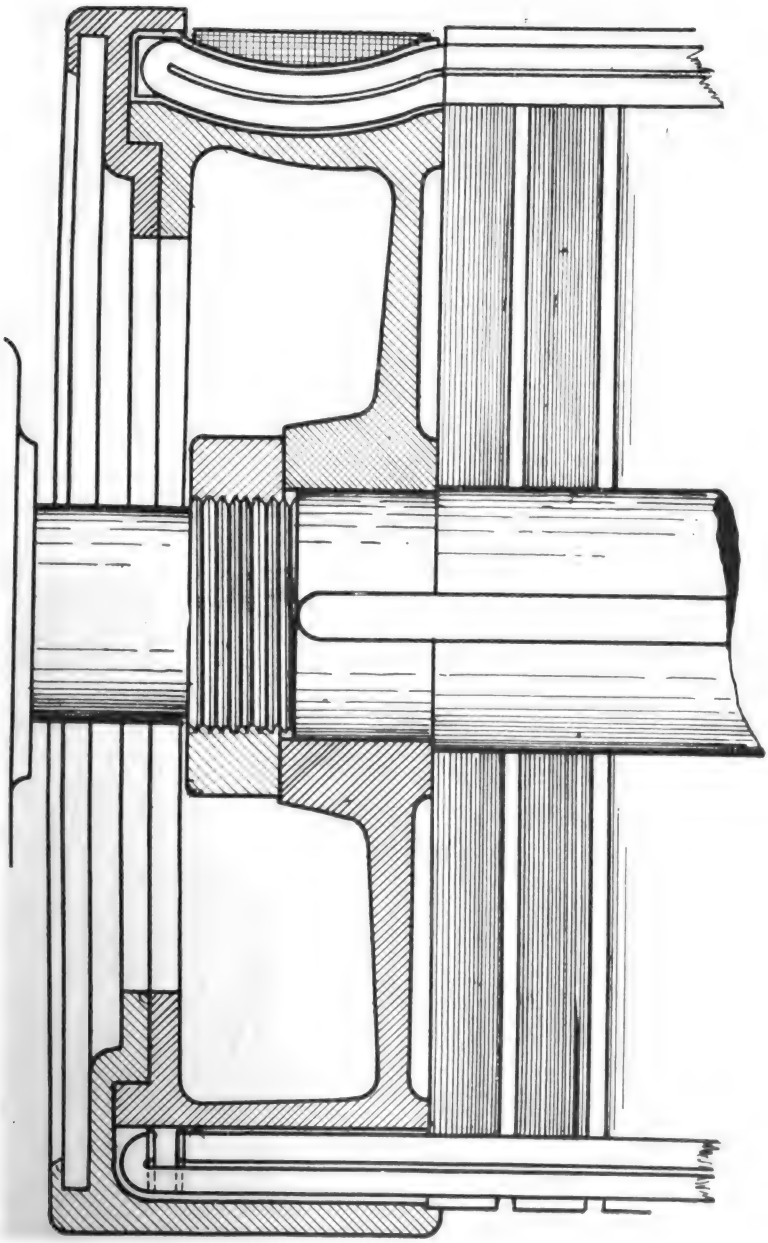
FIG. 11.

years afterwards, continuous-current machines only were built. The original turbo-dynamo was built to run at 18,000 r.p.m. A longitudinal section of the revolving part of this machine is shown in Fig. 11. The armature was 3″ diameter, and the construction was very simple, being built up as shown in the drawing, making practically one solid core; the winding was all on the surface, this being kept in place by a binding of steel wire extending the whole length of the armature. The construction of the commutator, however, proved a more serious problem than did the armature, but the difficulties met with were satisfactorily overcome by the construction shown. It was built up of a series of cast bronze segments interlaced with steel rings threaded on to a sleeve. With this construction the whole of the commutator was supported against radial stresses from one end to the other, so that there was little chance of trouble arising from high bars. This general design of generator was adopted for machines up to 30 or 40 k.w., but as the demand arose for larger machines modification in the design was found necessary. "Gramme" armatures were tried for machines of two or three hundred kws., but these were soon superseded by a modified construction of the drum type.

With continuous-current generators (for electrical reasons) it is not advisable to have the armature tunnel wound, but preferably in open slots. This leads to the difficulty of holding the conductors against the centrifugal force attendant with high speeds. Binding wire is often resorted to, but this construction is always, in the writer's mind, a very questionable solution of the problem. It is, as a rule, reliable, however, and considering the number of continuous and alternating current machines that are now running with this method of securing the winding, comparatively few accidents take place. Also it is difficult to secure, and solder must be resorted to. In the event of a short circuit happening, this solder is very liable to give out, causing considerable trouble and expense for repairs. The majority of continuous-current generators to-day are constructed with *semi-enclosed slots*, a keypiece being driven in on top of conductors. This construction is satisfactory for the core of the armature, but the end windings require some other method of support. Fig. 12A shows one method of end winding with binding wire. This construction, as will be seen, is so designed that where the heaviest load comes on the conductors the thickness of binding wire is greatest. The alternative to the above construction now generally used is shown in Fig. 12B, the end winding being kept in position by bronze end bells. This construction has the advantage that repairs can be readily attended to. The greatest difficulty so far that has been experienced with this class of end bell is the securing of suitable material. With cast bronze it is difficult to ensure the material being homogeneous; and further, the physical properties are never so sure in this class of material as in the case of binding wire or forged material; so that in a construction of this kind for the end bells it is advisable, where possible, to use rolled material.

The form of commutator now adopted in nearly all continuous-current turbo-generators follows the line shown in Fig 13. This

A



B

FIG. 12

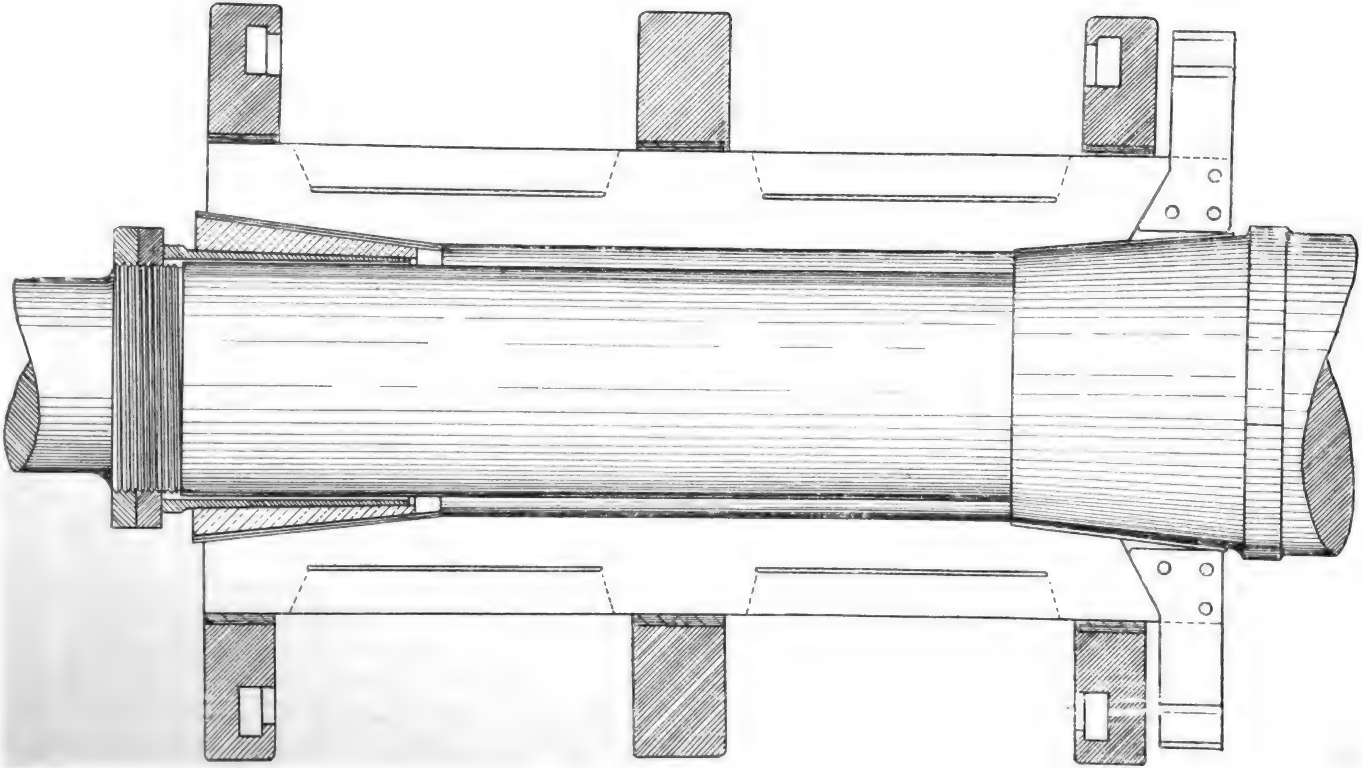


FIG. 13.

construction is an improvement on the original design shown in Fig. 11 from a mechanical standpoint, as the whole can be more correctly machined than was the case in the old design. Further, this design permits of the commutator segments being each in one throughgoing piece. The method of building up this commutator is as follows :—The segments are built up with intervening layers of mica and clamped together. The mica is then tied round the outside at the place where the shrink rings are to be fitted ; the steel rings then shrunk on, and the whole machined inside and out. The commutator is then supported on cones at each end, which fit tightly on to the shaft.

Owing to the wear that is bound to take place on such commutators, allowance must be made so that when the commutator is worn down to a certain extent, the segments do not become too weak to support themselves between the rings, and in consequence bulge out, causing high bars. To eliminate this a good scheme is to design the bars so that at, say, half the original depth, they are stiff enough to carry themselves rigidly, and have sufficient cross section to carry the current without undue heating. In order that it may become apparent when it is time to stop truing up the commutator, a series of notches or grooves can be placed along the commutator segments indicating the limit for truing up. When this point is reached it is time for a new commutator. All overhanging mica, etc., should be turned off, as this has often been found to give trouble by collecting dirt.

The armatures of continuous-current generators can never be of so good a mechanical construction as the turbine spindle, and in consequence balancing troubles are more likely to occur here. This subject, however, will be more fully gone into later in the paper, but when designing armatures for this type of machine it is one of the most important things to take into consideration. Everything throughout should be so designed that when running there is as little unbalanced mass as possible, and where keyways are cut in the shaft, two should be provided diametrically opposite, in order to keep the shaft itself as uniform as possible. Provision should be made in all armatures for the speedy application of balance weights.

The design of satisfactory brush gear for turbo-dynamos presents many problems. It has been found that it is almost impossible to use carbon brushes on this type of generator, owing to the fact that the armature floats when running, thus causing the brushes to dance. *Metal brushes must, therefore, always be used,* and in consequence, unless commutating poles or compensating windings are adopted, the position of the brushes must be altered to suit small variations of the load. *In all modern turbo-generators commutating poles or compensating windings are adopted, thus ensuring fixed lead.* The adoption of compensating windings has, however, only been in use on turbo machinery for the last two or three years, and Messrs. Parsons previous to this adopted an automatic brush control whereby the position of the brushes on the commutator was adjusted according to the load. This device is in use on some of the largest continuous-current turbo-dynamos now in

operation. The pressure in the steam ring behind the poppet valve is found to be proportional to the load, so that by admitting steam from this point to the underside of a piston, which is loaded with a spring on the opposite side, the position of this piston is also dependent on the load. An arm from the brush-gear is connected to this piston, so that the position of the brushes on the commutator is thus controlled. The adoption of compensating winding eliminates the above complication, and it is now standard practice to adopt this method, thereby ensuring fixed lead at all loads.

Owing to the high speeds necessarily attendant to the design and construction of steam turbine machinery, continuous-current machines are not so applicable on account of commutation and other difficulties to this form of prime mover as those for alternating current, where the periodicity is not too low, and there are few reasons why they should not be more successful than the slow-speed type.

The first turbo-alternator of any importance was built by Parsons about 1888, and had an output of 75 k.w. The first machine, and those following it for many years, were of the revolving armature type, the construction being very similar to the original Parsons continuous-current dynamo. Among the last machines of any moment with revolving armatures were the 1,000 k.w. turbo-alternators of 4,000 volts for Elberfeld, built in 1899. The later type of revolving armature machines were tunnel wound, the end winding being held in bronze end caps similar to that shown in Fig. 12B.

During the last few years the demand for larger machines with higher voltages has necessitated the adoption of the rotating field type of alternator. With rotating field machines the design of the armature or stator differs little from that of ordinary slower speed machines. The design of the rotating fields, however, demands very careful consideration. They may be built up of—

(1) Laminated plates.
(2) Slabs of forged steel, say, about two or three inches thick.
(3) Solid core with poles bolted on.
(4) One solid piece.

All the above constructions are now adopted by different makers, and are not governed by any electrical conditions, so that the design is purely a question of mechanical stability. In large machines the peripheral velocity amounts to something like 300 feet per second. With this speed centrifugal stresses are very high, demanding the finest material possible for such work.

In view of the exceptional duty called upon in large rotors the solid type has been adopted by one or two makers in preference to the built-up construction. This construction is perhaps the safest, and presents less possibilities of balancing troubles, although there are no reasons why the built-up construction should not give excellent results.

The British Westinghouse Company, in their designs for the 5,500 k.w. turbo-alternators for the London Underground Railway Co.,

in order to be on the absolutely safe side, adopted the solid construction. These rotors run at 1,000 r.p.m. The outside diameter is 67⅝ in., and the peripheral velocity of the pole faces 294 feet per second. The field itself is a solid forging of Whitworth fluid-compressed steel, the centre being bored out to admit the high carbon steel shaft. The sides of the poles are milled out to admit the windings, ventilating ducts being also milled out.

As in continuous-current work special care must be taken with the winding of the rotors so that the possibility of the shifting of the conductors is reduced to a minimum, and further, owing to the great weight of these rotating fields, the shafts should be as stiff as possible to prevent whipping, which points to another advantage of the solid pole construction as it materially stiffens the shaft. The whole length of the poles themselves can be taken as being absolutely rigid, so that the only deflection that takes place is between the ends of the poles and the bearings.

In turbo-alternators, while the core and copper losses are slightly smaller than those of the slow-speed type, it is much more difficult to dissipate the heat on account of the much smaller radiating surface, so that careful consideration must be given to ventilation. To reduce as low as possible the loss by windage, smooth cores should be adopted where possible. In order to obtain ample ventilation two totally different methods may be adopted.

(1) As much exposed surface and free air way as possible.

(2) Machine entirely enclosed with forced ventilation.

Both these systems are now extensively used, and it is hard to decide which is preferable. The first has the advantage of being more efficient, but has the objection of being noisy. This noise is almost entirely eliminated in the enclosed machine, but tests have shown that with this type, to obtain sufficient ventilation a considerable amount of power is absorbed by the blowers, resulting in a somewhat less efficient machine.

The design of bearings for steam turbines and turbo-generators has necessitated a departure from the well-established lines, as experiments on bearing friction in ordinary steam-engine practice are of little use when applied to steam turbine work. The nature of the load on the bearings differs from that of steam engines by there being no pounding action; the dead weight only of the shaft must be taken care of. In turbine bearings we are confronted with the following conflicting conditions.

On the one hand the shaft should be sufficiently strong and rigid, necessitating large diameter journals, and the bearings must be sufficiently long to keep the pressure per sq. inch low, to allow of the oil being constantly renewed round the journal. On the other hand, the circumferential speed of the journal must be kept as low as possible to reduce friction. In order to make the whole length of the bearing effective, this length must not be excessive.

For very high speeds such as those used in small turbo-generators, where the shaft is not allowed the free whipping action as in the De

Laval machine, a special construction is necessary, as, owing to the uncontrollable whipping of the shaft, vibrations would be set up in a bearing of the ordinary type, which would in turn be transmitted to the machine and become a very objectionable feature. Mr. Parsons, during his early experiments, appreciated the fact that a special form of bearing was necessary.* The bearing would have to fulfil the following conditions :—

(1) It must allow a reasonable lateral movement of the shaft, and must follow the path of the shaft when tending to rotate about its own centre of gyration.
(2) It must have a certain amount of frictional resistance to transverse motion.

After various experiments the best result was obtained with a bearing consisting of a solid bush in which the shaft revolves. This bush was fitted with a collar at the one end and a nut at the other. Washers were threaded on to this bush, fitting alternately the bearing housing and the bearing bush ; lastly, a wide washer fitting both the bush and the block, forming a fulcrum on which the bush rested, while a spiral spring between the washer and the nut pressed all the washers together. With this type of bearing, should the rotating shaft be slightly out of truth, the effect is to cause a slight lateral displacement in the bearing bush, which is resisted by the sliding friction of each washer against its neighbour. The shaft being slightly elastic tends to centre itself about the fulcrum washer aforementioned. The gyroscopic forces brought into play by the rapid revolution of the shaft are influenced by the frictional resistance of the washers, and the shaft tends to assume a steady state of revolution about its own principal axis without setting up undue vibration.

This form of bearing was used for many years, but was eventually modified by a much simpler construction. The washers were substituted by a series of concentric tubes fitting loosely over one another. The spaces between these tubes are filled with oil, making an efficient damper. Considerable vibration may therefore exist at the centre bush without being perceptible at the outer casing.

For small turbines and generators with high speeds down to about 2,000 r.p.m., this bearing is almost universally used, and gives entire satisfaction. For large machines, however, with speeds below that mentioned, the rotating elements can be sufficiently well balanced to run smoothly in solid bearings. The small bearings referred to above are invariably of bronze, but with solid bearings, cast iron, white metal lined have shown themselves to give excellent results. Even with large bearings for the comparatively slower speeds the bearings must be allowed a certain amount of give ; this can be done either by easing off the bushes towards the end, or fitting the whole bearing into a spherical seat. With white metal bearings the danger of course lies in their

* *Journal Inst. Elec. Eng.*, vol. 33, p. 794, "The Steam Turbine as applied to Electrical Engineering," by the Hon. C. A. Parsons, G. G. Stoney, and C. P. Martin.

running out should the oil supply at any time fail. With bronze bearings the effect would be very severe seizing of the shaft, doing possibly a considerable amount of damage to the whole spindle. With good white metal bearings the writer has seen the oil supply fail, the only result being a slight wearing of the bush, causing no damage whatever to the shaft. As regards the metal for the journal itself, the experiments of O. Lasche, of Berlin,* go to prove that the metal employed, whether of nickel steel, Siemens-Martin steel, or mild steel, has little influence on the degree of friction. With regard to the degree of smoothness and to the facility for taking a highly polished surface, Mr. Lasche points out that microscopic examinations of the outside faces, even with magnifications of 100 times, did not reveal any great difference in their structure. The co-efficient of friction for mild steel was found to lie between those of the harder materials, Siemens-Martin and nickel steel. The experiments clearly show that there is no great gain by using nickel steel. Further, the nickel steel after a somewhat prolonged service showed larger pores than a mild steel journal of equal service.

The effect of clearance has a marked influence on the efficient working of turbine bearings. It also has a large influence on the amount of total friction and also on the running and safe working conditions. In bearings with small clearances a relatively great amount of power is required to overcome the friction, even if the shaft is not very heavily loaded. Friction between the shaft and the oil, between the oil and the bushes, and between the oil particles themselves has to be overcome. In consequence it is better to ease the bearings considerably on the upper half; this materially decreases the friction and allows much smoother running. If the shaft is well balanced the upper half of the bearing can be entirely dispensed with, and this is practically done in many instances, a clearance of $\frac{1}{16}$ inch being allowed on the top half of the bearings. However, should the shaft have any tendency to whip, an uncovered bearing of this kind leads to trouble, as it offers no resistance to the shaft moving laterally. For this reason instead of cutting the whole of the top of the bearing away it is safer to allow a strip of the bearing to remain along the top, thus holding the whole shaft.

The peripheral velocity in turbine bearings is necessarily very considerably higher than in ordinary steam engine practice, velocities of 50 feet per second being regular practice. The load per square inch, however, must be kept very low. In steam turbine practice to-day it is usual to allow a constant of 2,500 for the peripheral velocity in feet per second multiplied by the pressure per square inch on the bearings. This in some cases is raised as high as 3,000. Experimental bearings have been run, however, with a peripheral velocity of 70 feet per second and a pressure of 70 lbs. per square inch, thus giving p.v. of 4,900. The crux of the whole question is the facility for dissipating the heat, and for this reason as much of the bearing as possible should be

* *Traction and Transmission*, vol. vi., part 5, p. 33, "On Bearings for High Speeds," by O. Lasche.

in contact with the outer walls, provided, of course, that the outer walls themselves are also free to dissipate heat. Water-cooled bearings are very often resorted to in very large machines, the principal advantage of these being that in a turbine of the Parsons type the heat from the H.P. end of the turbine is transmitted to the bearing, the water-cooled bearing isolates this heat from the bearing proper. In machines where there is no close contact with steam-heated surfaces, the bearings working within the limits mentioned, viz., a constant of 2,500 to 3,000 for p.v. can be and are being run satisfactorily without water cooling. An ample oil supply, however, should be given; in fact, the supply of oil in turbine bearings should not be restricted. In steam turbines the oil leaves the bearings uncontaminated by water or other matter, and can be returned to the cistern and re-used, so that there is little loss by providing an ample oil supply. The usual European practice in turbine work is to allow about ·05 gallons per square inch of bearing surface per minute.

The question is very often brought up as to whether ball bearings are suitable for turbine work. Ball bearings at moderate speeds give excellent results, but they do not stand the test of high speeds; they are noisy even with small balls. This is very pronounced when the peripheral velocity of the revolving body is about 30 feet per second, so that on the whole they are not suitable for high-speed work, nor are they as safe as the plain bearing.

Considerable trouble is often experienced in the successful balancing of steam turbines and turbo-generators. To reduce the possibilities of such trouble to a minimum, the following points must be taken into consideration in the design of the machine:—

(1) The materials adopted should be as homogeneous as possible.
(2) The design should be absolutely symmetrical.
(3) Where possible, all parts should be machined inside and out.
(4) The shaft must be sufficiently stiff to resist undue whipping.
(5) Special care must be taken with the windings and insulations to ensure rigidity when running.
(6) Where possible, the normal running speed should be below the "critical speed." If this is not possible, the normal speed should be reasonably higher, so that the critical speed, except when running up or shutting down, is never reached in ordinary operation.

Referring to item

1. Where possible, *forged steel* should be used throughout in the construction of the rotor; if this is adhered to considerably less trouble is likely to present itself than would be the case were castings used.

2. It is obvious that the design of any rotating part for high speed should be as symmetrical as possible.

3. Not only should the parts be machined inside and out, but this operation should be performed with the utmost accuracy.

4. In connection with the design of a shaft of sufficient strength to resist whipping, the length between the bearings should be kept down

to a minimum. This length, however, is determined by the maximum peripheral velocity allowable on the rotor. With turbine spindles of the Parsons type the ratio of the length between centres of bearings to the diameter at the centre of the shaft is often as high as 11, and in small generators 6 to 8. It is often necessary, therefore, to apply balance weights at, or about, the centre as well as at the ends before smooth running can be accomplished. In continuous-current machines provision is therefore often made for applying balance weights to the inside ring of the commutator (Fig. 13). With generator rotors of 1,000 k.w. and upwards this ratio rarely exceeds 3, and in the majority of cases in very big machines about 2·5. With this ratio balancing troubles, with the reasonably low speeds now adopted, are never very serious.

5. One of the greatest troubles experienced in maintaining good balance of turbo-generators is due to the shifting of the conductors. This often happens after the machine has been running some time and as the insulation dries it gets compressed by the centrifugal force on the conductors. The slightest shifting of these conductors is likely to throw a big rotor considerably out of balance. Should the machine at one time or another run away and attain the speed of, say, one and a half times the normal running speed, the severe load resulting is often sufficient to throw the whole rotor out of balance. In view of the above too much consideration cannot be given to the design of conductors adopted, their method of securing, and the actual manner in which they are secured in the works.

6. In all bodies revolving at high speeds there is a period at which excessive vibration will take place, and is called the "critical or whirling" speed. It falls at a point at which the natural period of transverse vibration of the shaft loaded with the rotating element is equal to the impulses given to the shaft by the centrifugal force acting on a slightly bent shaft; at this speed steady operation of the shaft is impossible. Mathematical investigations of this phenomenon have been carried out and published by Professor Dunkerley* and others.

The critical speed for any shaft is given by Foster† as :—

$$N = 9{\cdot}55\sqrt{\frac{Fg}{W}}$$

Where

W = Weight of rotating mass and a portion of the shaft.
F = Force in pounds weight necessary to bend the shaft one foot at the point of attachment of the wheel.

The above formula is for a shaft of diameter D feet.

Then

$$F = \frac{3EI(a+b)}{a^2b^2}$$

* *Philosophical Trans. Royal Soc. of London*, vol. 185 (1894), A.P. 279. "On the Whirling and Vibration of Shafts," by S. Dunkerley, M.Sc.

† *Eng. Review*, vol. 10, No. 5, "The Theory of Steam Turbines," by F. Foster, B.Sc.

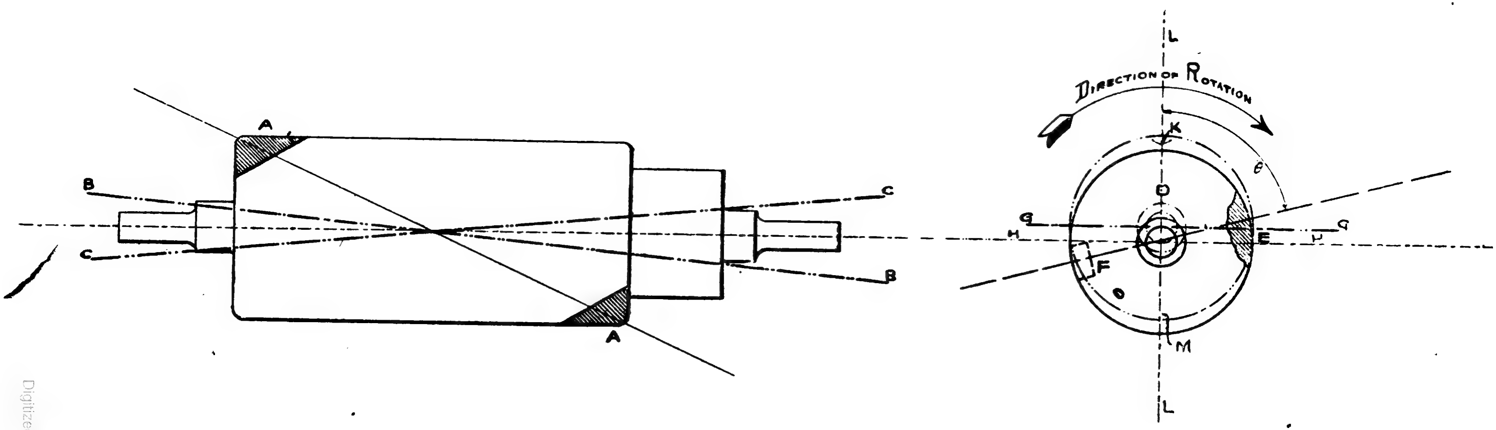


FIG. 14.

where

E = Modulus of (direct) elasticity in lbs. per sq. foot.
I = Moment of inertia of the cross section.
= $0{\cdot}0482D^4$.
a and b = Distances in feet of the wheel from the bearings.

The following formula is given by Behrend* for turbo-generators:—

$$N_1 = \sqrt{\frac{KEI}{ml^3}}$$

In this case N_1 is the angular velocity at critical speed.

E = Modulus of Elasticity.
I = Moment of inertia of the shaft in relation to bending.
M = Mass of rotating element.
L = Distance between bearings.
K = Constant whose value is about 75.

Where possible, in the construction of the rotating parts for turbo-generators static balance of the respective parts should always be resorted to before assembling. Again, the whole body should be statically balanced before being run. If this is done, a considerable amount of trouble is often saved on the testing floor. If, however, the drum or body of similar construction shows perfect balance on the knife edges, it is no criterion so far as correct running balance goes. According to Fig. 14, the spots marked AA may be diametrically opposite, but when running the body would tend to revolve about the centre line CC at low speeds, and BB at very high speeds. Running balance can therefore only be arrived at by the cut-and-dry method. This is to run the motor up to speed and mark each end of the shaft with a coloured pencil. Referring to the diagram, if the pencil mark shows most prominently at the point D, this means that the actual centre line of the shaft during the period of marking lies in the plane GG instead of the normal HH. In very slow running machines the heavy weight E would only fall at the point K in the plane LL. At very high speeds, say 5,000 r.p.m. and upwards, the weight would still fall in the plane LL, but at the point M. When this condition of affairs is reached, it may be said that the mass is revolving about its true centre. In ordinary turbine work, however, with the reasonable speeds now adopted, we find the weight falling between these two extremes, so that the angle θ is determined by the weight of the mass and the speed of rotation. This angle in ordinary turbine work generally falls within the first 90° and more commonly within 60°. If the part to be balanced is run by a motor a quick method of determining this angle is by running the motor up to speed in opposite directions, marking the shaft in each case. A mean can then be found which will at once indicate the correct position for applying the weight.

* *Electrical Review* (N.Y.), vol. 45, No. 11, p. 376, "Steam Turbine Generators," by B. A. Behrend.

In balancing, if the rotor is considerably out of balance, one is very often much tempted to apply considerably more weight than is necessary. If the weights are applied at the periphery of the body, which has a velocity of, say, 300 feet per second at a radius of one foot, the actual weight applied is multiplied by the centrifugal force 3,000 times. Very small weights, therefore, have considerable effect in throwing the whole body back into balance.

In conclusion, the writer is aware that many of the most essential features in the successful design and construction of steam turbine machinery have not been dealt with; among them may be mentioned the securing of the blades, glands, coupling and governor gear; but he hopes that the few points brought forward will form sufficient basis for an interesting discussion.

Mr. Miller. Mr. T. L. MILLER: I would like to know more regarding what I consider one of the weak points of steam turbines—the attaching of blades. I have been much impressed by the strong mechanical construction of the blades in the Curtis turbine, which are cut out of the solid. The author remarks that trouble is likely to arise with the footstep bearing due to failure of oil supply, and I should suggest that an accumulator in the service would probably meet the difficulty, but I do not know if such an arrangement is in use anywhere. I would also point out that to counteract the radiation of heat from the turbine to the generator in vertical machines there is a fan which produces a counter current of air to keep the machine cool.

Mr. Bailie. Mr. J. D. BAILIE: I am able to give some figures in connection with the vertical Curtis turbines at Harrogate which bear out the author's remarks that little floor space is gained by the adoption of the vertical machine. I do not approve of building the bedplate into concrete, owing to the fact that any expansion which may take place in the bedplate will probably cause fracture in the foundation. Girder foundations are quite satisfactory if properly designed and braced together. With regard to the balancing of spindles, during my eleven years' experience with Parsons turbines it was very exceptional that I ever had to balance the turbine spindle after it had left the works. For all Parsons journals mild steel was adopted in preference to nickel steel. In the design of the cylinders, distortion is considerably reduced by thickening up the metal. Referring to the design of the double-flow Westinghouse machine, Parsons' original machines were double-flow, but these are obviously not as economical as the single-flow, as they consist of two machines of half the power, the blade height being consequently only half and the clearance percentage much greater. The author refers to the disadvantages of throughgoing shafts, but at the same time the design of the Westinghouse Company which has this feature has much in its favour. In conclusion I may mention that few alternators at the present day have their conductors secured by binding wire.

Mr. Lindley. Mr. H. LINDLEY: I should like to ask if there is ever any spring in the shafts of turbines after machining? I consider that a breakdown of

the oil pump would prove quite as serious in the case of the horizontal turbine as it would with the vertical machine. Mr. Lindley.

Mr. F. H. WHYSALL: I have no experience in the manufacture of turbines, but have had a good deal to do with the running of turbo-generators. I agree with the author that the generator gives most trouble, but this is not excessive. The Manchester Corporation machines have run for three winters; the machines are 1,800 k.w., the peripheral speed of commutator 6,000 ft. per minute, and they only require turning up every twenty months. With regard to the oil temperatures, superheating has increased the working temperature from 130 to 150° F., and no trouble has been experienced. My experience is that vibration troubles can be entirely eliminated by balancing the rotating parts. Mr. Whysall.

Mr. MILES WALKER: In reply to Mr. Bailey's inquiry as to the Metropolitan turbines, I may state that these machines have run without a single stop, and are never shut down unless required. A large number of practical experiments was made to determine the best design, and naturally some of these were failures. Mr. Parsons is no doubt a believer in practical experiments, judging from the number he has made. In any case, a reasonable man will judge a machine by its performance under working responsibility, and not by workshop experiments. The 50 per cent. overspeed tests on the Westinghouse machine have failed to affect a single blade. The disadvantage of solid blades is that if anything happens to these, repairing becomes a much more serious item. With carbon brushes half a thousandth of an inch play causes chattering, whereas a metal brush is entirely satisfactory. Mr. Walker.

Mr. LONDON (*in reply*): With reference to Mr. Miller's remarks, I do not think that blades cut out of the solid are commercially satisfactory. As Mr. Walker has pointed out, should anything happen to one or more of the blades by fouling, at the time when the rotating member was in the crane for instance, the repair becomes a much more expensive item. Tests have been carried out with blades caulked in at the Westinghouse works showing a factor of safety of about 10. Referring to the radiation in vertical machines, I think that even with the forced ventilation mentioned by Mr. Miller, a certain amount of heat must be conducted from the turbine to the generator through the feet. In reply to Mr. J. D. Bailie's remarks about thicker cylinder material, however thick the material is, it is necessary to have flanges at the horizontal joint of the cylinder, which have a tendency to throw the cylinder out of line when heated, so that to balance this ribs should be provided round the cylinder. Mr. Bailie has apparently misunderstood my remarks with reference to the balancing of turbine spindles. Once a spindle is balanced it is very seldom necessary to rebalance it, but it is the initial balancing that is often so very difficult with long spindles or with spindles of unhomogeneous materials. I am aware that the double-flow machine is a repetition in principle of Parsons' early machines, but for large machines such as those adopted nowadays the shorter blades are a mechanical advantage instead of a disadvantage, and tests have shown that the loss by extra clearance is inappreciable. Mr. London.

Mr. London. As regards the throughgoing shaft, the design of the Westinghouse spindle is very different from that adopted by Rateau or Zoelly, since the plates at the end, connected to the drum, have a considerable effect in stiffening the whole shaft. In reply to Mr. Lindley, it sometimes happens that spindles do spring slightly after machining, especially if they are very long, but they can be very easily straightened by gentle caulking. I do not consider that an oil failure in the horizontal machines is likely to cause as much trouble as with the vertical machines, as the duty on the bearings is entirely different.

ORIGINAL COMMUNICATION.

ON SHUNT RESISTANCES AND TEMPERATURE COMPENSATION FOR AMMETERS.

By ALBERT CAMPBELL, B.A., Associate Member.

The use of shunts with moving-coil ammeters is of great value for measuring direct current, and such instruments are now being very widely used. The measurement of very large currents can be carried out with very great precision when suitable low resistance shunts (of accurately known values) are available. In the practical use of such shunt resistances several interesting problems present themselves, and I propose to discuss one or two of these in the present paper.

§ 1. *Temperature Compensation in Shunt Ammeters.*

The usual arrangement of ammeter and shunt is that shown in Fig. 1. In this figure the instrument G is connected to potential points A and B of the shunt S, r representing an added resistance (usually inside the case of the instrument).

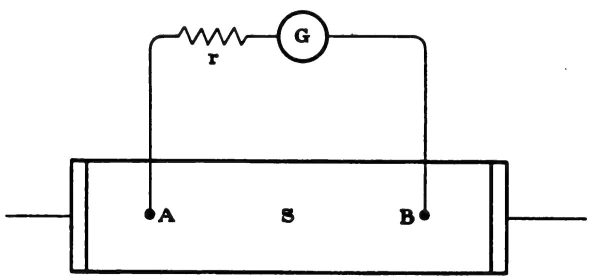


FIG. 1.

With such a combination the following conditions are desirable :—

1. The voltage drop on S should be as small as possible, otherwise much power may be wasted, and for large currents the shunt become inconveniently large in size.

2. The current through G should be as small as possible, *i.e.*, the resistance $r + G$ should be as large as possible. One reason for this is in order that the resistance of the leads and contacts at A and B may be rendered as nearly negligible as possible.

3. S should be of material having very small resistance temperature coefficient.

Condition (3) can easily be attained, and in what follows I shall assume the resistance of S to have a negligible temperature coefficient. There are, however, difficulties in the way of carrying out Conditions (1) and (2) thoroughly. If the voltage drop is reduced too much, slight differences of temperature at the various junctions in the circuit cause thermo-electric voltages which may seriously affect the readings. Conditions (1) and (2) are also limited by the difficulty of getting the instrument sufficiently sensitive. In order to get the maximum sensitiveness, sometimes the added resistance *r* is omitted and the number of turns in the moving coil of G is increased. The result of this is that the circuit A G B is entirely of copper, and the temperature coefficient of the whole combination with respect to the main current is $-0{\cdot}4$ per cent. per degree C.

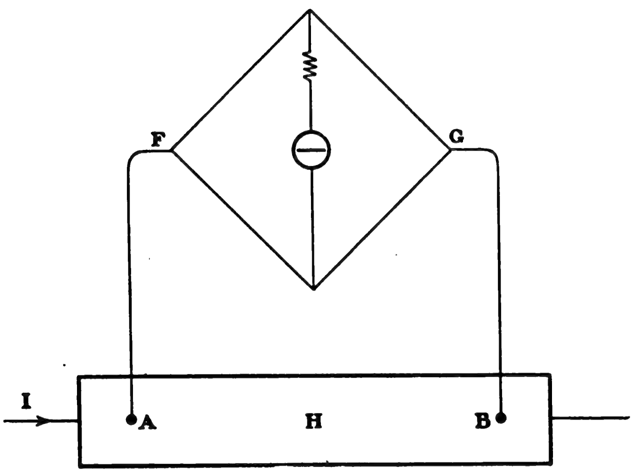


FIG. 2.

Most frequently a compromise is made between low voltage drop and temperature coefficient. In order to get over the difficulty as far as possible, I obtained some years ago a practical solution of the problem by the plan shown in Fig. 2.

Here the moving coil voltmeter (which I shall call the *cross circuit*) is connected across the opposite corners of four resistances as in a Wheatstone's bridge, the other two corners being connected to the potential points of the shunt carrying the current to be measured. It will be convenient to allude to the composite circuit A F G B (excluding the shunt H) as the *bridge circuit*. Usually the current taken by the bridge circuit is small compared with the current in the shunt. In what follows I shall first discuss this case, and afterwards notice the more general one. Since the shunt is assumed to have negligible temperature coefficient, we have the potential difference from A to B

practically proportional to the main current I for all ordinary temperatures. The instrument will thus have the same temperature coefficient for the voltage drop from A to B as for the current to be measured. Accordingly I shall now proceed to find the temperature coefficient of the instrument relative to the potential difference at the ends of the bridge circuit.

This coefficient is the fraction of itself by which the reading of the instrument is increased when the temperature rises 1° C. while the voltage across the bridge circuit is kept constant, *i.e.*, it is the ratio of the increase of the reading to the original reading. In symbols, if D_1 be the reading when the temperature is 1° C. hotter, and D be the original reading, the temperature coefficient $\beta = \frac{D_1 - D}{D}$.

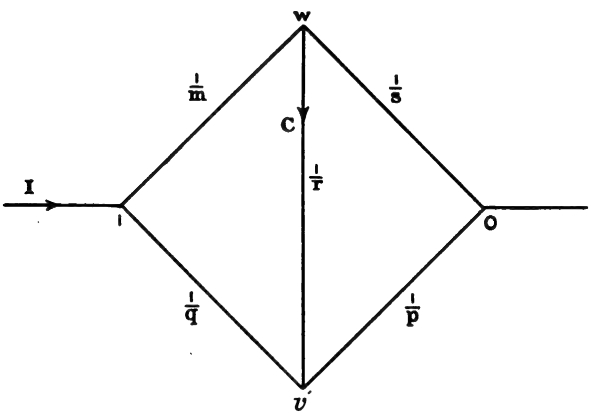


FIG. 3.

Let the general case of a bridge circuit be represented by Fig. 3, where the respective branches have resistances as marked, *i.e.*, *Conductances m, s, p, q,* and *r*; the resistances having temperature coefficients M, S, P, Q, and a respectively.

Let the potentials at the corners be 1, w, o, and v; the main current and the cross current being I and C respectively. By Kirchhoff's Law

$$(1 - w)\,m + (v - w)\,r + (0 - w)\,s = 0$$

and

$$(1 - v)\,q + (w - v)\,r + (0 - v)\,p = 0.$$

Let $w - v = V$, *i.e.*, the voltage between the ends of the cross circuit. Then we have

$$v\,(m + s) + V\,(m + r + s) = m$$

and

$$v\,(q + p) - V\,r \qquad = q,$$

and thus

$$V = \frac{mp - qs}{(p+q)(m+s) + r(p+q+m+s)} \quad . \quad . \quad . \quad . \quad (1)$$

Now, keeping constant the voltage on the ends of the bridge circuit, let the temperature rise 1° C., causing V to change to V_1. Then

$$V_1 = \frac{mp(1-M-P) - qs(1-Q-S)}{(p+q-pP-qQ)(m+s-mM-sS) + r(1-\alpha)(p+q+m+s-pP-qQ-mM-sS)}.$$

Let β = total temperature coefficient of the cross circuit (the instrument) relative to U, the voltage on FG (here 1 volt). Then

$$\beta = \frac{V_1(1-\alpha) - V}{V} \doteqdot \frac{V_1 - V}{V} - \alpha,$$

whence we obtain

$$B \doteqdot \frac{(p+q)(mM+sS) + (m+s)(pP+qQ) + r(pP+qQ+mM+sS) - (p+q)(m+s)\alpha}{(p+q)(m+s) + r(p+q+m+s)}$$

$$- \frac{mp(M+P) - qs(Q+S)}{mp - qs} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

This is the complete solution in the general case.

For practical temperature compensation it is usually convenient to make the opposite bridge arms equal, having one pair of high, and the other pair of negligible, temperature coefficient. Thus let

$$p = m \quad \text{and} \quad M = P = n\,a,$$

also

$$q = s \quad \text{and} \quad Q = S = 0.$$

Then equation (2) reduces to

$$\beta \doteqdot \alpha \frac{s^2 - m^2 - 2mn(s+r)}{(m+2r+s)(m-s)}. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

When

$$s^2 - m^2 - 2mn(s+r) = 0 \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

then $\beta = 0$, and there is practically complete compensation for temperature.

This simpler case is shown more clearly in Fig. 4.

We have (Fig. 4)

$$\beta \doteqdot \alpha \frac{(b^2-1)a - 2bn(1+\alpha)}{(a+2b+ab)(1-b)}. \quad . \quad . \quad . \quad . \quad . \quad . \quad (5)$$

For complete compensation (*i.e.*, $\beta = 0$)

$$\frac{b^2-1}{b} = \frac{2n(1+\alpha)}{a} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

It is important to consider how much greater the total current (I)

is than the current (C) which deflects the instrument. We can easily show that in Fig. 4

$$\frac{\mathrm{I}}{\mathrm{C}} = \frac{1 + 2a + b}{1 - b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (7)$$

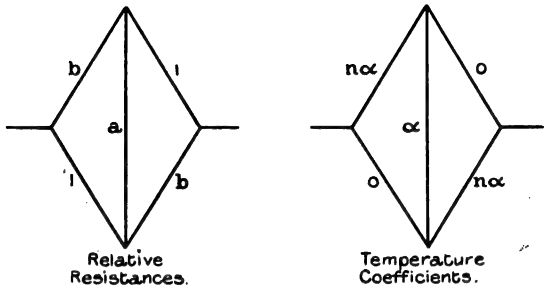


FIG. 4.

Also, from equation (1), in this simple case we have

$$\mathrm{V} = \mathrm{U} \cdot \frac{a(1 - b)}{a + ab + 2b} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (8)$$

where, as before, V = voltage on instrument
and U = voltage on shunt.

Practical Example.—Let the resistances be in proportion to the numbers shown on Fig. 5, those marked | being of manganin, and the other three of copper, with temperature coefficient of 0·004 per degree C.

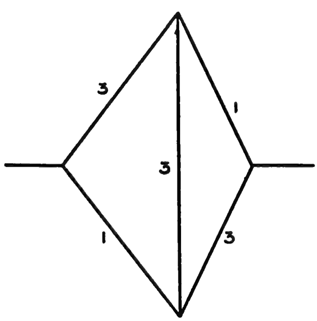


FIG. 5.

Thus $a = b = 3$,
$\alpha = 0{\cdot}004$,
$n = 1$.

Hence from equation (5) we have

$$\beta \doteqdot \alpha \frac{8 \times 3 - 6 \times 4}{18 \times (-2)} \doteqdot 0,$$

i.e., the combination has a *zero temperature coefficient.*

$$\text{Also} \qquad U = -3\,V,$$
$$\text{and} \qquad I = -5\,C.$$

Thus we see that complete compensation can be obtained when the voltage across the shunt is no more than three times that across the instrument. In actual practice a maximum voltage-drop of 0·075 volt on the shunt allows 0·025 volt on the terminals of the voltmeter (whose circuit is entirely of copper). The total current taken is five times that required to work the instrument, and in most cases this is not excessive. Owing to the increased current the leads from the potential points must be suitably thick.

I should mention that in practice the compensation is very exact. Messrs. Elliott Bros., who use the compensator largely in their moving coil ammeters, have kindly given me the following details of one of their "C" Type Weston ammeters fitted with a compensator :—

Compensator Arms, Copper 2 ohms each, Manganin 2·5 ohms each.
Instrument 0·90 ohm.
Leads 8 ft. of 70/40 flexible cord.
Maximum Voltage without Compensator, $V = 0{\cdot}03$ volt.
„ with „ $U = 0{\cdot}065$ volt.
„ Current without „ $C = 0{\cdot}033$ ampere.
„ „ with „ $I = 0{\cdot}072$ ampere.

The following table gives the results of a series of tests on this instrument at various temperatures :—

Temperature. Deg. C.	Reading of Ammeter.	Actual Amperes.
19·4	25·00	24·95
22·8	„	24·94
24·7	„	24·93
26·6	„	24·95
30·0	„	24·96
36·6	„	25·00

It will be seen that even for the wide temperature limits here given the maximum error from the mean reading is not more than 0·2 per cent. This indicates that the effect of varying temperature is practically negligible.

To revert to the most general case mentioned early in this paper, when the current to be measured is small, the fraction of it taken by the compensator may be so large that the above formulæ are in-

adequate, for the resistance of the whole "bridge circuit" has a temperature coefficient which is necessarily positive; in the simpler case discussed above, this coefficient is equal to

$$\alpha \frac{(1-b)^2 a + 2n(1+a)^2 b}{(1+2a+b)(a+2b+ab)} \quad . \quad . \quad . \quad . \quad . \quad . \quad (9)$$

The complete formulæ are complicated, but they show that even in the most general case compensation can usually be attained.

In all the foregoing I have assumed that the temperature coefficient of the instrument is due entirely to its resistance. In practice this is not quite the case, for a small part of the coefficient is due to the variation (with temperature) of the elasticity of the controlling springs and the magnetic flux from the permanent magnet. The sum total of these effects, however, often appears to reduce the temperature coefficient and thus make compensation easier.

§ 2. *Inversion of Potential and Current Points.*

The following is a well-known theorem on networks of linear conductors:—

"If A, B, M, and N be four points in a network of linear conductors, and if a current C entering at A and leaving at B cause a potential difference V across M N, then an equal current C entering at M and leaving at N will cause an equal potential difference V across A B."*

The theorem holds for any network of linear conductors (with any form of boundary), and hence for any number of superimposed networks. A conducting sheet may be supposed to be built up of an infinite number of similar networks of infinitely fine uniform mesh. For an isotropic sheet these must be so placed that at every point the elementary linear conductors are equally distributed as to direction. Thus we see that the theorem can be extended to any conducting sheet and also to any solid conductor.

The application of this reciprocal relation to shunts with potential points is of some practical importance.

In Fig. 6 let G and H be two strip resistances, identical in every respect, with copper ends of negligible resistance and potential terminals on the strips as shown. If G and H are connected in series in the way shown in the figure, so that a current C enters and leaves G by the copper ends, but enters and leaves H by its potential terminals, then the voltages u and v will be equal, *i.e., the voltage drop across the potential terminals of G will be equal to the drop across the copper ends of H.* Thus the potential and current terminals may be *interchanged* without altering the "working value" of the resistance. [By "working value," I mean u/C or v/C.] In practice it is well to make sure that there is no undue heating if the potential terminals are used for the current. It is interesting to notice that in Fig. 6 the current stream-lines are totally different in G and H. To show the

* For the proof of this theorem see Maxwell (*Elec. and Mag.*, vol. i., edition 2, p. 371), or A. Gray (*Phil. Mag.*, vol. xxiv. p. 278).

contrast I have indicated roughly on G′ and H′ the stream-lines in G and H.

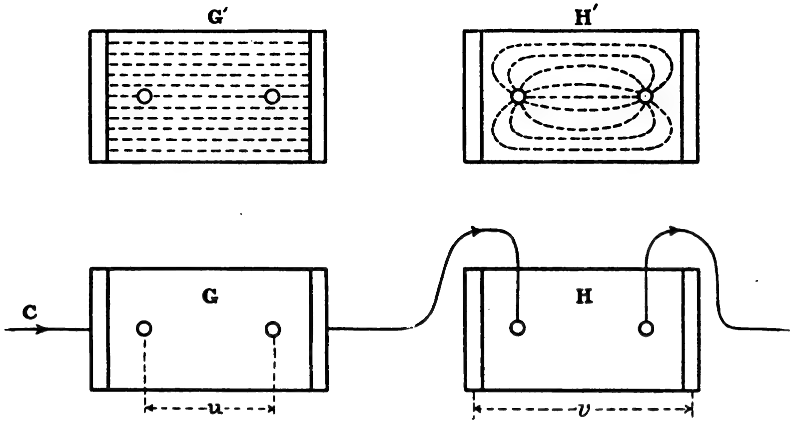


FIG. 6.

§ 3. *Shunting a Low Resistance.*

A very convenient way of making the final adjustment of a low resistance is to make it slightly high and then to shunt it with another resistance relatively high. This shunt may be put across either (1) the Current Terminals or (2) the Potential Terminals. The effect is quite different in the two cases, the first case being, as will be seen, much the simpler of the two.

CASE (1).—*Shunt across the Current Terminals.*

In Fig. 7 let A and B be the potential terminals, and let the current C entering by M and leaving by N cause the voltage drops U and V as shown. In Fig. 8 let the same resistance be shunted by s, giving, for the same current, U_1 and V_1, as shown.

$$\text{Let} \quad \frac{U}{C} = P \quad \text{and} \quad \frac{V}{C} = R;$$

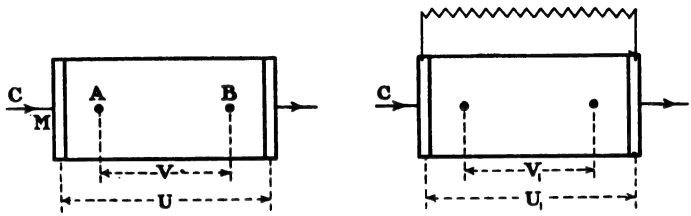
$$\text{also} \quad \frac{U_1}{C} = P_1 \quad \text{and} \quad \frac{V_1}{C} = R_1.$$

$$\text{Now} \quad \frac{V_1}{U_1} = \frac{V}{U} \quad \text{and} \quad P = \frac{U}{V} \cdot R;$$

$$\text{also} \quad U = CP \quad \text{and} \quad U_1 = C \cdot \frac{Ps}{P+s}.$$

$$\text{Therefore} \quad R_1 = \frac{V_1}{C} = \frac{V}{U} \cdot \frac{Ps}{P+s} = \frac{R\left(\frac{V}{U}\right)s}{R + \frac{V}{U}s} \quad . \quad . \quad (10)$$

Thus, when the shunt s is applied to the current terminals M N, the working value of the resistance A B will appear as if shunted by $\frac{V}{U} \cdot s$. The ratio $\frac{V}{U}$ may be found, once for all, by two observations on the



FIGS. 7 AND 8.

unshunted resistance. Usually, however, it may be got with sufficient accuracy from the ratio of the lengths A B and M N (since the stream-lines are straight). Because of this simple method of finding the ratio V/U, this way of shunting is easier than (2) for the purposes of adjusting.

CASE (2).—*Shunt across the Potential Terminals.*

In Fig. 9 let the same current C, entering and leaving at A and B respectively, cause a voltage drop u across A B. Then, by the reciprocal relation mentioned above, the voltage drop across M N will be V.

Now let the shunt s be applied to the potential points giving for the same current the voltages u_1 and V_2 as shown in Fig. 10.

By the reciprocal relation the current C entering and leaving by the current terminals (Fig. 11) will give the same voltage V_2 across the potential terminals.

$$\text{Let} \quad r = \frac{u}{C}, \qquad R_2 = \frac{V_2}{C}, \qquad \text{and as before} \qquad R = \frac{V}{C}.$$

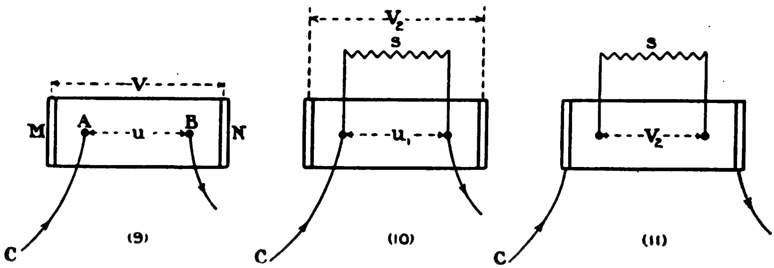
$$\text{Therefore} \qquad r = \frac{u}{V} \cdot R.$$

$$\text{Now} \qquad \frac{V_2}{u_1} = \frac{V}{u} \qquad \text{and} \qquad u_1 = C \cdot \frac{r s}{r + s}.$$

$$\text{Therefore} \qquad R_2 = \frac{V_2}{C} = \frac{V}{u} \cdot \frac{r s}{r + s} \qquad \textit{in Fig. 9.}$$

$$\text{Thus} \qquad R_2 = \frac{R\left(\frac{V}{u}\right) s}{R + \frac{V}{u} s} \quad \ldots\ldots\ldots\ldots \quad (11)$$

Hence when the shunt s is applied to the potential terminals A B, the working value of the resistance A B will appear as if shunted by $\frac{V}{u}$ s.



FIGS. 9, 10, AND 11.

As in Case (1), two observations of voltage with the unshunted resistance give, once for all, $\frac{V}{u}$. In this case, however, $\frac{V}{u}$ cannot be got from the ratio of the lengths M N and A B, for the stream-lines corresponding to u are not straight lines, but are like the curved ones shown for H′ in Fig. 6. In practice the common example of Case 2 is when the shunt s consists merely of the millivoltmeter or wattmeter shunt put across the potential points.

From formula (11) it can be seen in any particular case if the error thus introduced can be neglected or not.

I may remark that in some shunts the potential terminals practically coincide with the current points. The first adjustment of these is not so easy, but the simplification is a great advantage.

In conclusion, I have to thank Mr. Alexander Russell for his kindness in checking for me all the mathematical work in this paper.

ORIGINAL COMMUNICATION.

THE DISSYMMETRY OF A THREE-PHASE SYSTEM.

By ALLAN B. FIELD, M.A., B.Sc., Associate.

One of the most salient features of a three-phase electrical system is its general symmetry; in this respect it excels the four, or three, wire two-phase system. There is, however, always the element of dissymmetry introduced by the fact that there are two possible directions of phase rotation, only one of which can be adopted at a time.

This fact, which appears so commonplace when its effect is, say, the starting of a motor in the one direction rather than the other, is often also the cause of discrepancies of a nature which is unexpected, so apt is one to look upon a balanced three-phase supply voltage as entirely symmetrical. A slight unbalancing of the load is usually the means of bringing the dissymmetry to light, and it then appears in addition to that one, immediately due to the disturbance of load, which is looked for.

In this article a few examples of the effect will be given and some of its bearings on three-phase transformer design considered.

Perhaps one of the simplest examples that can be mentioned, and one in which no additional dissymmetry is introduced, is that shown in Fig. 1. Here a symmetrical load is represented, being fed by a symmetrical three-phase supply: three similar current transformers (T) are inserted, one in each leg, and the three secondaries are connected in similar ways to the succeeding phases as shown. Measuring the voltages between *a*, *b*, and *c*, we should find them to always form a symmetrical three-phase system, but their magnitudes would depend upon the direction in which the alternator was revolving. In fact, if the voltage 1—Y, etc., were, say, 100 each, the transformer ratio and load such that the secondary voltages were also 100 each, and the power factor of the load equal to 0·866, we should have with the one direction of phase rotation, zero voltages across *a*, *b*, and *c*, and with the other direction 300 volts each. With the first direction of rotation

the voltages would be very sensitive to small changes of power factor.

An interesting practical case in which the dissymmetry occurs was pointed out by the writer's brother, Mr. M. B. Field, some years ago,*

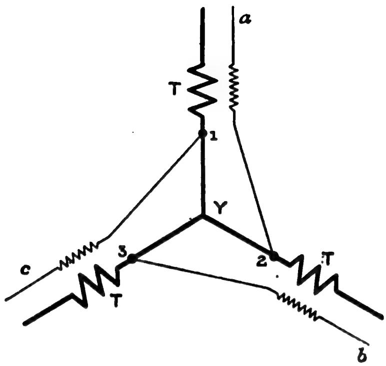


FIG. 1.

viz., that of a three-phase transmission line supported on single cross arms.

Consider such a line having two of the conductors equidistant from the third, but all three in one plane, the line carrying a balanced three-phase current. It will be readily admitted that the middle wire, being uniquely placed, may operate under slightly different conditions from

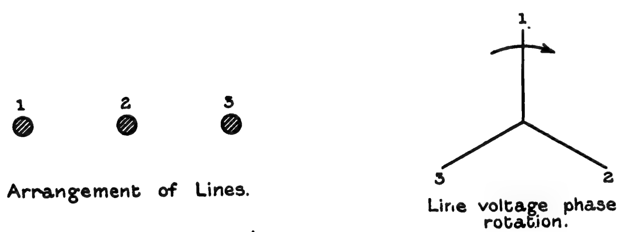


FIG. 2.

the outside ones, but it is not so immediately evident that there is an essential difference in this respect between the two outer ones; that, in fact, the inductive drop along the right-hand wire has not the same magnitude as that along the left-hand one, or, in other words, that there is a nett positive transference of energy every cycle, taking place inductively from the other two wires taken together—to the left-hand one

* See *Journal Institution Electrical Engineers* (England), vol. xxx. p. 567.

when the phase rotation is as shown in Fig. 2,* and the reverse with a changed phase rotation.

Such, however, is the case. The reactive voltage induced in line No. 1 may be considered as the sum of two, viz., half that due to the current No. 2 flowing in the circuit consisting of lines Nos. 2 and 1, and half that due to the current No. 3 in the circuit consisting of lines Nos. 3 and 1. Of these two the latter is the greater, independently of the direction of phase rotation, while their phase displacements behind V_1 are $(150° + \alpha)$ and $(30° + \alpha)$, taken in this, or the reverse order, according to the direction of phase rotation. ($\cos \alpha =$ the power factor of the load, current lagging.) Hence the reactive voltages induced in lines Nos. 3 and 1 will have components in phase with V_3 and V_1, which components will be respectively $\pm$ and $\mp$ according as the phase rotation is c.c. or c.

The effect is naturally not of an alarming magnitude; in fact, the reactive voltage per line differs from what it would be if one outside wire were brought into position to complete the equilateral triangle, by the addition of practically the following voltages per mile per ampere, where f signifies the frequency in cycles per second :—

For line No. 1 : $0{\cdot}0014 f$ volts situated 90° in advance of the current in No. 3.
For line No. 2 : *Nil.*
For line No. 3 : $0{\cdot}0014 f$ volts situated 90° in advance of the current in No. 1,

which corrections, it is interesting to note, do not depend on the size of wires or distance apart, but only on the frequency.

For example, in the case of such a line consisting of three No. 0 B. & S. wires, 18 inches apart, carrying a 25 cycle current of 40 amperes, the reactive volts per mile in the three lines would be about 10·26, 9·5, and 10·26, at angles 83·2°, 90°, and 96·8° respectively, behind their corresponding currents. So that, adding an ohmic drop of, say, 21 volts, and taking a power factor of unity, the component line drops per mile in phase with the main voltages, which practically represent the effective line drops, would be about 19·8, 21, and 22·2 respectively, showing just an appreciable difference (11 per cent.) between lines 1 and 3. With an inductive load the total drops would be greater, up to a certain point, and the discrepancies a trifle less. At 60 cycles the discrepancy would be of the order of 25 per cent., the exact figure depending on the line voltage. Taking an unpractical case with larger wires or higher frequency, an effective *rise* might occur in the one line.

Another interesting example, and one which, in some respects, might be considered the magnetic analogue of the above electrical case, is that of a three-limbed core-type three-phase transformer, in which the centre lines of the three limbs are in one plane, an arrange-

* The Fig. 2 is intended to indicate phase relations between the currents 1, 2, 3, represented by $\sin pt$, $\sin\left(pt + \frac{2\pi}{3}\right)$, and $\sin\left(pt + \frac{4\pi}{3}\right)$ respectively.

ment commonly adopted for the sake of economy of construction. A reference to Fig. 3 will explain the type of magnetic circuit referred to.*

In such a transformer the one winding is usually Y-connected, and the other Δ. Dealing with the Y-connected side—say the primary, so that the winding corresponding to each leg of the supply voltage is confined to one limb—we have evidently a slight dissymmetry as regards the magnetic reluctances corresponding to the three phases, and also as regards the distribution of core loss between them, on account of the middle limb being uniquely placed.

But in addition to the middle leg behaving differently from the other two, such a transformer shows a discrepancy between the behaviour of the two outer legs, which difference is reversed on changing the phase rotation. The effect is swamped when the trans-

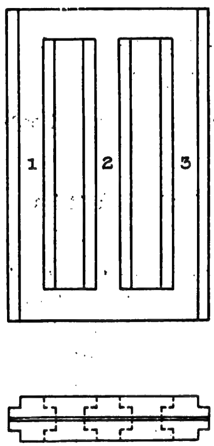


FIG. 3.

former is loaded, and in no way affects its satisfactory operation, but is very evident on open secondary circuit, and may amount to 5 per cent. or more difference of magnetising current between the two phases corresponding to the outer legs of the core, and a very much larger difference of watts supplied to these two phases. The displacement of the Y point is naturally insignificant.

Such discrepancies are quite often credited to slight differences of treatment during manufacture, but the effect of such can be immediately separated from those in question by making two measurements, reversing the phase rotation for the second.

* The ordinary shell type of three-phase transformer also furnishes an example. but the core type is here chosen as it exhibits a slight discrepancy in the magnetic reluctances as well as in the division of core loss.

As an example, the following figures (Table I.) refer to a twenty-five cycle three-phase three-limbed transformer of the type described above, running unloaded. The transformer was rated at something over 150 k.w. and the winding used at 480 volts Y connected.

TABLE I.

Phase Rotation.	Amperes.						Transformer Volts.					
				Approximate Angular Distances apart.								
	1	2	3	2–3	3–1	1–2	2–3	3–1	1–2	1–Y	2–Y	3–Y
C.	7·28	5·02	6·77	105·4°	138·4°	116·2°	477	470	474	274	278	275·5
C.C.	6·85	4·95	7·1	113·4°	138·4°	108·2°	476	471	477	276	279·5	272

By clockwise phase rotation is meant a direction, with respect to the numbers 1, 2, 3, as shown in Fig. 2, and similarly in the remainder of this article. The approximate current angles above are estimated from the ammeter readings given, and the Y voltages are 120° apart within less than a degree. The middle leg of the core is denoted by No. 2.

By considering the way in which the core loss is supplied, the discrepancy between the two outer legs is even more marked than is indicated by the currents, the watts supplied to the lagging one being only some 55 per cent. or so of that received by the other. The middle phase takes a little less than 30 per cent. of the total core loss watts.

We thus see that such a transformer, whether Y or Δ connected, running with open secondary circuit, is equivalent to three loads correspondingly connected, which have the interesting characteristic that the values of the resistance and reactance of two of them are actually dependent on the direction of phase rotation. It is shown below that in the case of any Y-connected load, of which one leg is different from the other two, all three currents are in general different, though two are interchangeable on reversing phase rotation. The present case, however, is distinct, and of a more interesting nature, as the phenomenon is not caused by any displacement of the Y point, and would occur with a Δ connection fed directly with a symmetrical voltage. In fact the change of effective resistance that here takes place is a real change, not merely a rearrangement of potential differences; it would not occur if the three magnetic circuits were independent.

It is easy to follow the matter out analytically and see how an unequal subdivision of the core loss of the yokes among the three legs brings this about. A short consideration from this point of view is given at the end of this paper.

The above test results, although not entirely consistent (being taken under commercial conditions), show the class of effects obtained. The displacement of the Y point, however, is almost all due to the slight want of balance shown in the supply voltage, which originated in the step-down transformers used.

Such distortions of supply voltage, however, which one frequently comes across, are independent illustrations of the point in question. For instance, the following (Table II.) represent two types. These figures refer to the supply to a stationary phase changer, loaded in an unbalanced manner to the extent of about 9¼ k.w. (non-inductive on the secondary). Here the unbalancing occurs, almost entirely, in the stepping down from the alternator to the phase changer, and is due to the different phase displacements of the currents producing different reactive drops and rises in the transformers (ΔΔ or ΔY connected).

TABLE II.

Phase Rotation.	Amperes.			Volts.		
	1	2	3	2–3	3–1	1–2
C.	15·5	47·5	62·8	177	189·5	178
C.C.	17·5	44·8	63·4	174·5	165	180
C.	37·1	69·5	34·1	172·5	171	156
C.C.	34·6	69·5	37·2	158	171	173·5

It is unnecessary to go into the exact load conditions prevailing here, as the point is illustrated without; suffice it to say that in each of the two cases, the only change of connections between the two readings was the interchanging of any two of the high-tension alternator leads, that is at a place in the circuit where the voltage was practically a truly balanced three-phase one. Changing all three alternator leads, keeping the phase rotation the same, produced no effect.

In the first pair of readings the effect shows itself in the 3–1 voltage, this being boosted or lowered some 7 per cent., according to the direction of phase rotation. The second pair is an example of the interchanging of volts 2–3 with 1–2 on reversal.

These cases are given as being of interest, not that there is any difficulty about their explanation, but because one is not always ready at first sight to expect such results from simply reversing the direction of rotation of the alternator.

In the same way we have in general, in the case of any Y-connected load of which one leg differs from the others, a fixed discrepancy occurring in connection with the odd leg, and also a difference between the other two legs, depending on which is the leading one,

The way in which this occurs is easily seen analytically, and it will be sufficient here merely to give the result :—

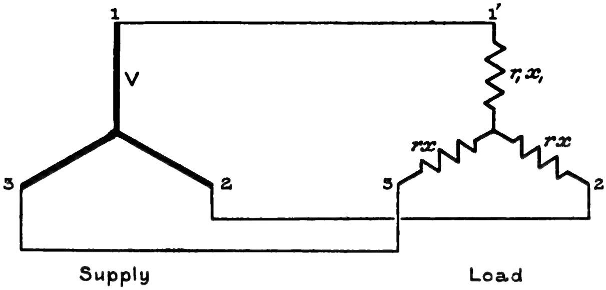


FIG. 4.

Take a symmetrical supply voltage as in Fig. 4, where the voltage of leg No. 1 of the Y is V sin pt, referred to the Y point as zero ; and a Y-connected load of which the branches 1, 2, 3 have resistance and reactance $r_1\,x_1$, $r\,x$, $r\,x$, respectively, so that No. 1 is the odd branch. Assume the voltage of the Y point of the load to be

$$v \sin pt + v^1 \cos pt.$$

Then writing

$$\rho \text{ for } r_1 \frac{I^2}{I_1^2} - r \qquad \text{where } I^2 = r^2 + x^2$$

and

$$I_1^2 = r_1^2 + x_1^2$$

$$\xi \text{ for } x_1 \frac{I^2}{I_1^2} - x$$

we have,

$$\frac{v}{\rho(3r+\rho)+\xi(3x+\xi)} = \frac{v^1}{\rho(3x+\xi)-\xi(3r+\rho)} = \frac{V}{(3r+\rho)^2+(3x+\xi)^2}$$

and hence the voltage across each branch of the load, the three currents, etc.

It is evident that v^1 will not in general be zero (unless $r_1\,x = r\,x_1$), and that therefore in such a load, all three currents and leg volts will, in general, be different, but that those corresponding to the two similar legs of the load will be interchangeable by reversing the phase rotation of supply voltage.

If the discrepancy is only in the reactance and is small, the above reduces to

$$\frac{v}{x} = \frac{v^1}{r} = \frac{-V(x_1 - x)}{3I^2} =$$

similarly if all three reactances are equal and $r_1 - r$ is small, it becomes

$$\frac{v}{r} = \frac{v^1}{-x} = \frac{-V(r_1 - r)}{3I^2} =$$

This effect leads at once to a simple and useful voltmeter method of quickly determining the direction of phase rotation in any case, by inserting in one lead, in series with the load, a small reactance—if more or less non-inductive load, or resistance if considerably inductive—the method being sufficiently obvious without the formula.*

In the cases mentioned the dissymmetry is of but little practical importance, although perhaps of some interest. Cases, however, occur in which such effects are produced under load conditions, and become of importance.

Take the case of a stationary phase changer converting from three to two phase, and consisting of three single-phase transformers or a single three-legged transformer. Let the three primaries in either case be each confined to one transformer, or leg, and be connected in a regular Y or Δ; let the two-phase secondaries be built up by connecting in series a suitable number of turns from each transformer, or each limb in the case of the three-legged transformer, thus adding together components of E.M.F.'s in different phases to give the required resultant.

To construct such a phase changer we can choose any arbitrary phase relation between primary and secondary; say that leg B of secondary is to be θ degrees of phase ahead of leg No. 1 of primary voltage, and for every such relation there is an infinite number of combinations of secondary windings that will give a true no-load two-phase voltage of given amount.† The regulation, however, of the

* A current transformer run on open circuit for the few seconds necessary to take the reading, will often give enough reactance for the purpose, if a suitable one be chosen and the circuit be a low-voltage one. Inserting this in series with, say, leg 1 of the load as in Fig. 5, we have an apparent negative drop of voltage across the reactance when measuring from the leading phase, *i.e.*, voltage 2–1 is greater than voltage 2–4, or if the load is somewhat inductive we may instead compare $V_{24}-V_{21}$ with $V_{34}-V_{31}$, or for a very inductive load use a resistance in place of the reactance and so on. The writer has found this a very convenient method in some classes of work where it is necessary to quickly determine the phase rotation.

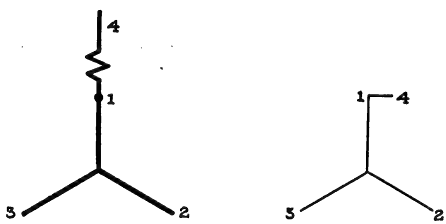


FIG. 5.

† To take a numerical example: In Table III., discussed later, are given two sets of "Regulation" tests for the case shown in Fig. 6, *i.e.*, $\theta = \pm 165°$ (the upper sign corresponding to a clockwise phase rotation). The two sets correspond to the following methods of building the secondary (see Table opposite):—

two secondary phases will, in general, be different the one from the other, and will depend on the direction of phase rotation of the supply voltage; the current also taken by the primary, with a balanced secondary load, will generally not be the same in the three phases, and the Y point, if the primaries are Y-connected, will be displaced, these effects also changing to some extent with reversal of phase rotation.

There is, however, *one* combination of secondaries for every arbitrarily chosen phase relation between primary and secondary, which will give a system in all respects practically independent of the direction of phase rotation for a balanced load, and for all power factors, provided the power factor is the same on the two phases. To meet the same condition for an unbalanced load we are further restricted in our choice of the phase relation between primary and secondary, and the solution for one load distribution will give results varying with the phase rotation when another load distribution is in force.

These facts are all evident on a short consideration of the matter; also that the dissymmetry will generally be greater with a Y primary than with a Δ one, and considerably greater with three separate transformers than with a single three-core one (Y connection).

In order to provide, in general, a system independent of the direction of phase rotation, we have two principal conditions to fulfil—(*a*) The proportions must be such that on non-inductive load the resultant secondary ampere turns on each limb, or in each transformer, is in phase with the corresponding induced primary voltage (neglecting minor terms). (*b*) The product of the numbers of turns of the two secondary phases of leg No. 1 of the core, added to the two similar products for the other two legs, should vanish. The above facts are fairly evident, and it is hardly necessary to enter upon a formal demonstration here. A few words, however, in explanation may not be out of place. Assume we have the phase-changer giving on no-load a true three- to two-phase transformation, and we now close the secondary circuit on a balanced non-inductive load, keeping a constant sym-

		Relative Nos. of turns from the three legs of the core.		
		1	2	3
First Set	Phase A	0	299	−816
	Phase B	−816	299	0
Second Set	Phase A	173	471	−644
	Phase B	−644	471	173

The negative signs indicate reversed connections.

By compounding these, graphically or otherwise, both methods will be found to give the same no-load results; and it will be seen that there is an infinite number of methods of building to produce the arrangement of Fig. 6.

metrical three-phase voltage impressed on the primary. Any disturbance of the secondary voltage system that takes place will be due to (1) CR drops, and (2) reactive voltages within the phase-changer. Leaving out of account the former, we are only concerned with magnetic leakages, and of these there are three sets to be considered. For the winding of each secondary phase on each leg we may consider a leakage flux that encircles that winding only. This set of leakages will produce a slight distortion of the secondary voltage system if an unsymmetrical method of building has been adopted ; but this effect will generally be inconsiderable unless the load is badly unbalanced. We may next consider a leakage flux encircling both secondary windings on each leg, and the effect of this also will be dependent on the direction of phase rotation. We can evidently, however, make the total effect of this zero by balancing one leg against another, *i.e.*, by making $a_1 b_1 + a_2 b_2 + a_3 b_3$ equal to zero (see below for notation). Finally we have the leakage flux of each primary winding which escapes all other windings: Consider the primary to be Δ-connected, then the current in each of its windings will be practically at 180° to the resultant secondary ampere turns on that leg of the core which it encircles, and will thus be represented, in the clock diagram, by a line which is situated, with respect to the two secondary voltages, in a position nearly unchanged by reversal of phase rotation. Such reversal will therefore be represented on the diagram by but little more than the reversal of the rotational arrow, or, in other words, primary currents that are leading with one direction of phase rotation become lagging with the other, and *vice versâ*, and consequently also reactive drops and rises interchange. If this effect is to be eliminated, the phase displacements of the primary currents with respect to their voltages must be zero (practically) when the secondary load is non-inductive ; further, if the design complies with this condition, then with an inductive load on the secondary a reversal of phase rotation will be represented on the clock diagram by, not only a reversal of the rotational arrow, but a shifting over of the primary currents, so that their phase displacements remain the same as before reversal. We have here left out of consideration the possibility of balancing the effect of primary leakage, against that of the second leakage mentioned, on account of these quantities being independently variable with the different spacings of windings required to suit various conditions. There is, of course, the further alternative of introducing auxiliary apparatus, external to the phase-changer, to correct these effects, since disturbances of the nature here discussed, depending on the values of the currents flowing, can be compensated by suitable self and mutually inductive series windings inserted in the secondary circuits. Apart, however, from the extra complication of any such arrangement, there are serious disadvantages, as the regulation of the whole system is impaired where the troubles are introduced, and again where they are counterbalanced.

We are thus left with the two conditions formulated above, and the composition of the secondary to fulfil these is easily found.

Using the ordinary clock diagram, take the phases of secondary voltages Nos. A and B to be represented by i and 1 respectively ($i = \sqrt{-1}$), while those of the 1, 2, 3 branches of the primary Y are similarly represented by $e^{i\theta_1}$ $e^{i\theta_2}$ $e^{i\theta_3}$ respectively, where $\theta_2 - \theta_3 = \theta_3 - \theta_1 = \theta_1 - \theta_2 = \pm\frac{2\pi}{3}$. (The line represented by 1 is drawn horizontally to the right, and θ is measured from this axis counter-clockwise. It will be noticed that θ_1 represents the lead of secondary phase B with respect to primary phase No. 1.) Take also the relative numbers of turns on the three legs, or three transformers, for phase A of secondary to be represented by a_1 a_2 a_3, and for phase B by b_1 b_2 b_3, these symbols denoting turns multiplied by volts per turn divided by the secondary voltage required. Let α represent the ratio of loads on the phases A and B for which we want to eliminate the dissymmetry.

We shall then have to satisfy the following conditions :—

To give the required secondary voltage

$$\begin{aligned} i &= a_1 e^{i\theta_1} + a_2 e^{i\theta_2} + a_3 e^{i\theta_3} \\ 1 &= b_1 e^{i\theta_1} + b_2 e^{i\theta_2} + b_3 e^{i\theta_3} \end{aligned} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$

To comply with condition (a) above

$$\begin{aligned} \alpha a_1 i + b_1 &= d_1 e^{i\theta_1} \\ \alpha a_2 i + b_2 &= d_2 e^{i\theta_2} \\ \alpha a_3 i + b_3 &= d_3 e^{i\theta_3} \end{aligned} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

where d_1 d_2 d_3 are defined by these equations. In the case, however, of a Y converted primary, these three quantities must necessarily be equal and hence the solution, with this primary connection, becomes restricted to the case of balanced loads.

Writing c_1 for $\cos\theta_1$, s_1 for $\sin\theta_1$, etc., these give :—

$$\begin{aligned} 1 &= a_1 s_1 + a_2 s_2 + a_3 s_3 \\ &= b_1 c_1 + b_2 c_2 + b_3 c_3 \end{aligned} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

$$\begin{aligned} 0 &= a_1 c_1 + a_2 c_2 + a_3 c_3 \\ &= b_1 s_1 + b_2 s_2 + b_3 s_3 \end{aligned} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4)$$

and

$$\alpha \frac{a_1}{s_1} = \frac{b_1}{c_1} \text{ and two similar ones;} \quad . \quad . \quad . \quad . \quad . \quad (5)$$

that is, seven equations; only six, however, are independent. We also wish to fulfil the condition (b) stipulated above, *i.e.*,

$$a_1 b_1 + a_2 b_2 + a_3 b_3 = 0. \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (6)$$

Using the first of equations (4), and eliminating b_1 b_2 b_3 from (3) and (5), we have :—

$$\begin{aligned} 0 &= a_1 c_1 + a_2 c_2 + a_3 c_3 \\ 0 &= a_1 k_1 + a_2 k_2 + a_3 k_3 \end{aligned}$$

where

$$k_1 = \frac{s_1^2 - c_1^2 a}{s_1}$$

and similarly k_2 k_3. Hence :—

$$\frac{a_1}{c_2 k_3 - c_3 k_2} = \frac{a_2}{c_3 k_1 - c_1 k_3} = \frac{a_3}{c_1 k_2 - c_2 k_1}.$$

After a little reduction we have :—

$$c_2 k_3 - c_3 k_2 = \pm \frac{\cdot 433}{s_1 s_2 s_3} \left[s_1 a + 2 (a - 1) s_1 s_2 s \right].$$

and hence

$$\frac{a_1}{s_1 a + 2 (a - 1) s_1 s_2 s_3} = \frac{a_2}{s_2 a + 2 (a - 1) s_1 s_2 s_3} = \frac{a_3}{s_3 a + 2 (a - 1) s_1 s_2 s_3} =$$

$$= \frac{b_1}{c_1 a - 2 (a^2 - a) c_1 c_2 c_3} = \frac{b_2}{c_2 a - 2 (a^2 - a) c_1 c_2 c_3} = \frac{b_3}{c_3 a - 2 (a^2 - a) c_1 c_2 c_3} =$$

$$= \frac{a_1 s_1 + a_2 s_2 + a_3 s_3}{1\cdot 5\, a} = \frac{1}{1\cdot 5\, a} \qquad (7)$$

Considering this result in connection with equation (6), we have

$$a_1 b_1 + a_2 b_2 + a_3 b_3 = - \left(\frac{1}{1\cdot 5\, a}\right)^2 12\, a\, (a - 1)^2 s_1 s_2 s_3 c_1 c_2 c_3$$

and if this is to vanish, we must restrict our choice of θ_1 by making any one primary voltage phase to be at 0° or 180° to one secondary ditto. It is clear, however, from an inspection of (7) that for no value of θ_1 will the relative numbers of turns be independent of a, and that, therefore, apart from (6) it is not possible to obtain an arrangement that will give results independent of the direction of phase rotation for *all* load distributions. One would then naturally design such a phase-changer with a view to a balanced load, *i.e.*, $a = 1$. In this case the above equations reduce to

$$\frac{a_1}{s_1} = \frac{a_2}{s_2} = \frac{a_3}{s_3} = \frac{b_1}{c_1} = \frac{b_2}{c_2} = \frac{b_3}{c_3} = \frac{1}{1\cdot 5} \qquad (8)$$

which satisfies condition (6) for all values of θ_1.

It may be well to here point out again that having fixed upon the phase relation between primary and secondary (*i.e.*, say fixed θ_1), there is an infinite number of designs giving the desired two-phase secondary voltage (no load). What we have found above is simply that particular design, out of all these, that also gives results independent of the direction of phase rotation. The numerical example given in Table III. should illustrate this sufficiently well.

From equation (8) it will be noticed that

$$a_1^2 + b_1^2 = a_2^2 + b_2^2 = a_3^2 + b_3^2 \qquad (9)$$

so that the same proportioning that is required by previous considerations gives also the resultant secondary ampere turns the same on the three legs (numerically), and causes the watts input to be equally divided among them, which is of some importance.

It is interesting to note also that

$$a_1 + a_2 + a_3 = b_1 + b_2 + b_3 = 0.$$

To give one example, the following figures (Table III.) illustrate the point and refer to a three-legged core with primaries Y connected, and with secondaries built up to give, on no load, a true two-phase voltage,

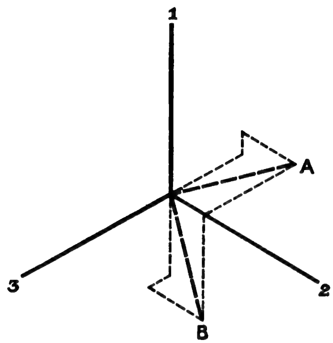


FIG. 6.

the two phases being at 45° to primary phase No. 2 ($\theta_1 = \pm 165°$, see Fig. 6). The first set of figures corresponds to the case in which turns from two legs only are used in building up each secondary phase—viz., the more obvious way of dealing with the matter, and a perfectly symmetrical one—while the second set is for proportions approximately as given by equation (8).

It will be seen that the first method would be entirely useless for practical purposes, on account of the prohibitive drop of voltage in the leading phase as load comes on, the other phase showing a slight rise of voltage, and of course these interchanging with reversal of phase rotation. In each case the secondary load was the same—a balanced non-inductive one. The secondary phases remained practically 90° apart on load with both arrangements, but with an unbalanced load the angle opened out or closed up several degrees, according as the excess load was on the lagging or leading phase, as indeed one would expect. Primary phase No. 2 corresponds to the middle leg of the core.

By "Secondary Regulation" is meant, the percentage drop in voltage on the secondary from no load to full load, with constant primary voltage.

The above considerations have shown how, for an arbitrarily chosen value of θ_1, to proportion the windings in order to meet the specified

conditions. We are still left with entire freedom as to the value of θ_1, and in the choice of this there are of course many other points to be considered which we need not enter into here, such as weight of secondary copper involved, mechanical limitations as to cross-connections, etc.

TABLE III.

Phase Rotation.	Primary Voltages.						Secondary Regulation.	
	2 – 3	3 – 1	1 – 2	1 – Y	2 – Y	3 – Y	Phase A.	Phase B.
C.C.	168	168	169	106	101	86·1	7·9 %	– 1·8 %
C.	169	171	170	88·4	101·1	107·3	– 1·5 %	6·9 %
C.C.	193	194	193·5	111·5	111·9	111·1	2·1 %	2·0 %
C.	193·5	194	193	111·5	111·9	111·5	2·1 %	2·1 %

With combinations not corresponding to equations (8), or their equivalent, some of the primary currents, with a balanced non-inductive load, may be leading with respect to the corresponding voltages, and hence excellent regulation be obtained on one or more secondary phases (taking the general case).

It is easy to see, however, that this would only be at the cost of much impaired regulation on the remaining phases.

An example of three- to two-phase transformation, using two single-phase transformers only and giving results independent of the direction of phase rotation on balanced load, is afforded by the Scott method of connection so commonly adopted. This does not come in the class considered above, as the three primary phases are not confined to separate transformers or limbs of one transformer. There is but little effect of the dissymmetry here, even on unbalanced loads.

Some figures were discussed above, showing the operation of an unloaded three-phase core type transformer (Table I.). The effects are more easily followed analytically, and it may be of interest to briefly consider the distribution of core loss watts among the three phases here. The expressions are given algebraically for the sake of simplicity and brevity, but their graphical equivalents are obvious for those who prefer entirely geometrical methods. Fig. 3 shows the type of core in question.

We will approximate to the magnetisation curve and effects of core loss (omitting their introduction of higher harmonics into the current) as follows: Assume the magnetisation and core loss ampere-turns per

cm. required to produce an induction $B e^{i\theta}$ to be given by $B g e^{i(\theta-\phi)}$. [*i.e.*, $g \sin \phi = \frac{10^6}{4{\cdot}02 f B^2}$ multiplied by the watts per kgm. corresponding to a maximum induction B and a frequency f cycles per second]. The angle ϕ will generally be of the order of $20^\circ - 30^\circ$ (average for the entire magnetic circuit).

Denote by b the effective length of each limb (including two joints) multiplied by the maximum induction in same, and by b^1 the maximum induction multiplied by effective length of one pair of yokes, *i.e.*, half the entire yokes.

We can consider the winding either Δ or Y-connected—for even if the latter, no distortion of the Y point can take place with a symmetrical impressed voltage, except by magnetic leakage, which will be entirely negligible on no load. The type of core considered necessitates a zero value of the sum of the three leg fluxes, and hence this restriction.

Take, then, for the phases of the induced voltages in legs Nos. 1, 2, 3—

$$e^{i\theta_1},\ e^{i\theta_2},\ e^{i\theta_3},$$

where—

$$\theta_2 - \theta_3 = \theta_3 - \theta_1 = \theta_1 - \theta_2 = \frac{2\pi}{3}.$$

The fluxes in the three legs will be given in phase by

$$-i e^{i\theta_1}, \quad -i e^{i\theta_2}, \quad -i e^{i\theta_3},$$

and in the yokes by

$$\begin{array}{ll} (2-3) \ldots\ldots & i e^{i\theta_3} \\ (1-2) \ldots\ldots & -i e^{i\theta_1} \end{array}$$

Let C_1, C_2, C_3, represent the currents multiplied by turns in the three legs.

Considering, then, the three magnetic paths, and the ampere-turns required for the several parts of them, we have—

$$C_2 - C_3 = g e^{-i\phi}\left[-i b (e^{i\theta_2} - e^{i\theta_3}) + i b^1 e^{i\theta_3}\right] = \\ -g e^{-i\phi}\left[\sqrt{3}\, b e^{i\theta_1} - i b^1 e^{i\theta_3}\right].$$

$$C_3 - C_1 = g e^{-i\phi}\left[-i b (e^{i\theta_3} - e^{i\theta_1}) - i b^1 (e^{i\theta_3} - e^{i\theta_1})\right] = \\ -g e^{-i\phi}\left[\sqrt{3}\,(b + b^1) e^{i\theta_2}\right].$$

$$C_1 - C_2 = g e^{-i\phi}\left[-i b (e^{i\theta_1} - e^{i\theta_2}) - i b^1 e^{i\theta_1}\right] = \\ -g e^{-i\phi}\left[\sqrt{3}\, b e^{i\theta_3} + i b^1 e^{i\theta_1}\right].$$

If the winding is Δ-connected these give the line currents.

It will be noticed that in line currents 1 and 3 the terms involving

the core loss in the yokes enter in with crossed phases, giving an angle less than 120° between these two currents, and disturbing the balance of watts. The No. 2 current is larger than the other two, and is symmetrically placed with regard to them.

If the winding is Y-connected, we have, in addition to the above equations—

$$C_1 + C_2 + C_3 = 0.$$

Hence the currents are in this case—

$$C_1 = -ige^{-i\phi}\left[(b + b^1)\,e^{i\theta_1} + \tfrac{1}{3}\,b^1\,e^{i\theta_2}\right].$$

$$C_2 = -ige^{-i\phi}\left[(b + \tfrac{1}{3}\,b^1)\,e^{i\theta_2}\right].$$

$$C_3 = -ige^{-i\phi}\left[(b + b^1)\,e^{i\theta_3} + \tfrac{1}{3}\,b^1\,e^{i\theta_2}\right],$$

showing the yoke core loss entering in again in a similar way, but this time increasing the angle between Nos. 3 and 1, and thus increasing the watts in the leader of these two legs.

The above results, although explaining the discrepancy in watts between the outside legs and the variation in angle between the two corresponding currents, do not indicate any difference of magnitude in these two exciting currents. Consider the effect of harmonics in the magnetising current corresponding to a sine impressed E.M.F.: The first that can come in with a Y connection is the fifth, and this will appear with a phase rotation the reverse of that of the fundamental: it will introduce a set of five times normal frequency currents having the same relation to one another as the fundamental set would have with a reversed phase rotation. The root mean square values of currents Nos. 1 and 3 will therefore remain equal, and similarly after introducing other harmonics. Nor, indeed, could one expect the presence of harmonics, in any circumstances, to explain a discrepancy of the order of 5 per cent. here.

It will be noticed, however, that in the simple treatment given above, the method of dealing with the joints in the magnetic circuit was only rough. In the first place, the effect of joints for flux circulating between legs 1 and 3 will be found to be greater than for flux circulating between the middle and either outer leg, if the way in which the yoke is built up be considered, and hence the allowance for joints has to be distributed among the limbs and yokes in a more involved way than was indicated above. Also the exciting current for the joints—which form quite an important item in this respect—will have a smaller value of ϕ than corresponds to the rest of the circuit.

Taking such effects into account in making a closer approximation, the current in the leading outside phase will be found to be increased relatively to that in the lagging one; in fact, taking the actual case for which figures were given in Table I. above, the estimated relative values of current and angles between them are not very widely different from the measured values.

The above will be sufficient to indicate the way in which these interesting effects creep in ; also how, from a set of reliable core loss test results with complete wattmeter readings, it would be possible to separate out the losses in various parts of the iron, determine the effects of joints, etc.

If the case of a *shell type* three-phase transformer be considered instead, it will be found that there is a closing up of the angle between the currents of the two outside phases, and therefore an extra share of the core loss going to the lagging phase in this case.

The writer is indebted to the General Electric Company of New York for permission to cite the test figures given in this paper.

NOTICE.

The following publications can be obtained from the Secretary, or from Messrs. E. and F. N. Spon, Ltd., 57, Haymarket, S.W. :—

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Section A (Physics)	5	0	18	0
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JOURNAL

OF THE

Institution of Electrical Engineers.

Founded 1871. *Incorporated* 1883.

VOL. 35. 1905. NO. 174.

Proceedings of the Four Hundred and Twenty-sixth Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Society of Arts, John Street, Adelphi, W.C., on Thursday evening, May 4, 1905—Mr. ALEXANDER SIEMENS, President, in the chair.

The minutes of the Ordinary General Meeting held on April 27, 1905, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following transfer was published as having been approved by the Council:—

TRANSFER.

From the class of Associates to that of Members—
Charles Vincent Bellamy.

Messrs. W. Henderson and T. A. Cunliffe were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected:—

ELECTIONS.

Member.

Waldo Arnold Layman.

Associate Members.

Harry Pigott Allison.
Frederick Fernie.
Harry Bryant Matthews.
Frank Edmund Stanley.

Students.

Walter de la Roche Bond.
Edgar Hardy.
Frank Philipp.
Alan Faraday Campbell Pollard.

Donations to the *Building Fund* were announced as having been received since the last meeting from Messrs. S. Evershed and H. C. Silver, and to the *Benevolent Fund* from Mr. H. C. Silver, to whom the thanks of the meeting were duly accorded.

Mr. A. M. Taylor's paper, read before the Birmingham Local Section on December 14, 1904, was read (in abstract) and discussed.

The meeting adjourned at 9.35 p.m.

BIRMINGHAM LOCAL SECTION.

STAND-BY CHARGES AND MOTOR LOAD DEVELOPMENT.

By A. M. TAYLOR, Member.

(*Paper read in Birmingham, Dec. 14, 1904, re-discussed in London, May 4, 1905.*)

SYNOPSIS OF PAPER.

(1) Importance of securing a motor load before other competitors come in. (2) "Continuous" *versus* "Intermittent" Motors—Typical cases considered—Estimated cost to the station of each class. (3) "Non-interest-paying" Motor Loads. Extent to which a motor load can be developed, on the basis of non-consumption during winter peak. (4) Station Plant (Motor Load) Limit dependent on Day Fogs. (5) Increase in Limit due to yearly development in Lighting Load. (6) Examination of Wright's Diagram and deductions therefrom as to Works Cost with a Motor Load. (7) General Summary of Results of Investigation as to Price, embodied in table. (8) Relation of Diversity Factor and Load Factor. (9) Elements of the Author's "Stand-by Loss" Diagram—Stand-by Losses in Engines, Boilers, Steam Pipes, Feed Pumps, Condensers, etc. (10) Lighting and Power combined development—Item for "Unproductive Capital" to be introduced among fixed charges—Diagram showing annual increase in Lighting and Power demand necessary to warrant a reduction in price on account of "Unproductive Capital" Charge. (11) Conclusions.

APPENDIX.

(1) Further details as to means adopted in "Stand-by Loss" Diagram to represent conditions of engines and boilers working in parallel on the load, and with unequal division of the load.

(2) Relation of Size of Station to Price per unit.

(3) Relative Costs of Gas, Oil, and Electric Motors.

STAND-BY CHARGES; AND MOTOR LOAD DEVELOPMENT IN CENTRAL STATION SUPPLY.

It will readily be conceded—at any rate among Electrical Engineers—that it is very essential, if a motor load of any magnitude is to be secured by Electric Supply concerns, that it should be secured at once. First, because the developments in other motors are going on so

rapidly that there may be no field for the electric motor supply in a few years' time; secondly, because this condition will be reached the sooner, the smaller the sale of electric power at present realised; thirdly, because the average consumer will the less readily make a change to another form of motive power when once he has experienced the conveniences of electric supply; and fourthly, because the electric lighting demand is sure to benefit by the increased sale of motive power, and there is no knowing what competition may be in store, in the near future, for this also.

The object of this paper is to stimulate inquiry into any possible means of obtaining better motor loads, or of reducing prices of electric energy, without incurring material capital expenditure in so doing. There are many stations in the country at the present time, the author is convinced, which are daily losing motor loads because they dare not take them on until they have the plant to deal with them during peak hours. Again, there are many towns where electrical engineers have almost come to the conclusion that, on account of their present total costs and interest charges, factory and other large motors having continuous loads are hopelessly out of their reach (unless possibly through the larger power companies), and have, so to speak, accepted the inevitable and settled down to the more thankful task of picking up all the intermittently-loaded and smaller motors that other competitors cannot show such a good case for.

It is, however, surely unworthy of the antecedents of electrical engineers that they should be thus content with the offscourings of other competitors; can they not make a bid for continuously-loaded motors also? It is true that in some towns an effort has been made to secure some of this class of load; but that more than the fringe of the load has been touched which, were it not for price, might be obtained, it would be unsafe to assert.

"Continuous" versus "Intermittent" Motor Loads.—Before proceeding to answer the question raised in the last paragraph, let us consider for a moment whether it is possible to tempt consumers having the continuous class of load to come on to the mains by offering an attractive rate—say 1d. per unit—and making up for a possible deficiency of profit by taxing the intermittent class of motors with a higher rate—say 2d. per unit. Such a method of charging has the valuable property that it emphasises the difference between the two classes of load, and attracts consumers by the low rate for the more favoured class. On the other hand, unless the lower rate offered is such as to show economy over gas or oil, few consumers will be added of the class most sought for, while some of the intermittent class of consumers will probably be lost who might otherwise have been gained. The author is also very doubtful whether such a low rate as 1d. unaccompanied by restrictions (see later) will pay in the majority of stations which are purely lighting stations, even when coupled, as it should be, with the condition of a high load factor.

Take, for instance, the case of a lighting station of the ordinary type in any moderate-sized town, and let it be granted (as the author

hopes to prove, later in this paper, to be the fact) that the overlapping of the motor and lighting loads necessitates extra plant and mains being put down in proportion to that overlapping, or nearly so. Assume, further, that *all* the station load consists of the class of motor under consideration at the time. Then :

Class I.—Motor Continuously Loaded to its Full Output.

For 9 hours per day (say 50 hours per week).

Maximum load of motor = 1 H.P. = 0·90 k.w. at consumer's terminals.
Average " " = 1 H.P. = 0·90 k.w. " "
Hours of running per annum = 9 hours per day × $5\frac{1}{2}$ days × 52 weeks = 2,600 (approximate).
Hours of running per quarter = 650.
Diversity factor (see later) = 1·0.
Units sold per annum = 0·90 k.w. × 2,600 hours = 2,340 units.
Units per H.P. installed, per quarter = 585.
Now 0·90 k.w. at motor = say £70* × 0·9 = £63 additional capital outlay on Generating Station and Mains.

Interest and Sinking Fund at 7 per cent. $\begin{cases} = 1{,}056 \text{ pence per annum} \\ = \dfrac{1{,}056}{2{,}340} = 0{\cdot}45\text{d. per unit.} \end{cases}$

To this we must add a proportion of the costs of Management, Salaries, and Office.

Taking an average of eleven towns which have lighting loads (only) of 2,000 kilowatts or under, the author obtains a value of 0·23d. per unit for this item.

It is difficult to fix the proportion of this which should be charged to an ordinary motor load. From an investigation of a particular case, however, I find that about half this sum depends upon the number of connections to consumers, and hence on their individual demands and on their diversity factor ; and the other half depends, though indirectly, upon the capital expended in the station and mains, in each case for a given number of units sold.

The average demand per consumer, in the case investigated, was 1·7 kilowatts, with a diversity factor of 2·0 ; hence in the case now under consideration, where the diversity factor is unity, the first part of the charge will be, for a 5-H.P. motor (consuming 4·5 k.w.) :

$$= 0{\cdot}115\text{d.} \times \frac{1{\cdot}7}{4{\cdot}5}\text{ k.w} \times \frac{1{\cdot}0}{2{\cdot}0}\text{ D.F.} = 0{\cdot}022\text{d. per unit.}$$

The second part of the charge, depending on the capital expenditure for a given number of units sold, will only be affected by the load factor of the station, and (for a station of equal kilowatt output) will be in direct proportion to this, hence :

$$0{\cdot}115\text{d.} \times \frac{15}{30}\text{ L.F.} = 0{\cdot}057\text{d. per unit.}$$

Total for *Management, Salaries, and Office* $\begin{cases} = 0{\cdot}022\text{d.} + 0{\cdot}057\text{d.} \\ = 0{\cdot}079\text{d. per unit.} \end{cases}$

* "Productive Capital" only (see later in this paper).

We have next to consider the item of Rent, Rates, and Taxes. Taking an average of thirteen towns which have lighting loads (only) of 2,000 k.w., or under, the author obtains a value of 0·14d. per unit. Now, in most municipal concerns, at any rate, rent is an almost negligible quantity, as the ground and the buildings are their own property. Rates are levied on the assessment of the property, and are of the order of 7s. in the £, taken on a value which is of the order of 10 to 15 per cent. of the gross earning capacity of the station, and only to some extent do they depend on the load factor.

Taxes, on the other hand, are of the order of 1s. in the £, and are levied on the net profit of the station, which, though seldom more than 15 per cent. of the gross revenue in a lighting station, would, with better load factor, be perhaps 20 to 25 per cent. of the gross revenue.

The relative values of the costs for rates and for taxes in an electric light station will thus amount to about 0·12d. and 0·02d. per unit (= 0·14d. total, as above).

The gross earning capacity of a station of 2,000 k.w. capacity, with a motor load only, would be less than with a lighting station at the rates suggested in the proportion of :—

$$\frac{30}{15} \times \frac{\text{say 1d. per unit}}{\text{say 4d. per unit}} = \text{say 50 per cent. of what it is now.}$$

$$\left.\begin{array}{l}\text{Hence the cost per unit}\\ \quad\text{for } \textit{Rates} \text{ only}\end{array}\right\} = 0{\cdot}12\text{d.} \times \frac{50}{100} \times \frac{15}{30} = 0{\cdot}030\text{d. per unit.}$$

$$\left.\begin{array}{l}\text{And the } \textit{Taxes}\\ \quad\text{will be, say}\end{array}\right\} = 0{\cdot}02\text{d.} \times \frac{15}{30} \times \frac{25\,\% \times 50\,\%}{15\,\% \times 100\,\%} = \text{say } 0{\cdot}01\text{d. per unit.}$$

Total for *Rates* and *Taxes* = say 0·040d. per unit.

The Net Profit, having to be earned on twice the load factor, will be only half the price per unit of that of a lighting station, which may be taken at 0·37d. (average of thirteen stations).

Hence it is safe to take :—$\frac{1}{2} \times$ 0·37d. = say 0·18d. per unit.

We thus get a total, exclusive of depreciation or of works costs, of, say, 0·75d. per unit. About depreciation the author forbears to say anything, as it is rather a vexed question ; but as regards works cost, let us assume the excellent figure of 0·70d. per unit, which is surpassed by comparatively few stations of 2,000 k.w. capacity which have not got a traction load, and we get a total cost to the consumer of 0·75d. + 0·70d. = 1·45d. per unit.

It will be noted that even this does not reach a "bed rock" price of 1d. per unit, which would only be warranted where the "works cost" was as low as 0·3d. per unit, or else where the plant was larger than 2,000 k.w., or had a good night load, and even then only in the case of motors consuming at least 585 units per H.P. installed per quarter.

We now come to

CLASS II.—MOTOR INTERMITTENTLY LOADED, WITH VARYING LOADS.

Maximum load = 1 H.P. = say 0·90 k.w. at consumer's terminals.
Average load = $\frac{1}{2}$ H.P. during hours of running = say $\frac{1}{2}$ k.w.

Hours of running per annum $= 4\frac{1}{2}$ hours per day $\times$ $5\frac{1}{2}$ days $\times$ 52 weeks $= 1{,}300$.
Hours of running per quarter $= 325$.
Units sold per annum $= \frac{1}{2}$ k.w. $\times$ 1,300 hours $=$ 650 units.
Units per H.P. installed per quarter $= 162$.
Now 1 k.w. at motor $=$ £70* additional capital outlay at generating station.

$$\text{Interest and Sinking Fund at 7 per cent. on £70} \left\{ \begin{array}{l} = 1{,}175 \text{ pence per annum} \\ = \dfrac{1{,}175}{650} = 1{\cdot}81\text{d. per unit.} \end{array} \right.$$

But this will be reduced by the value of the diversity factor.

This, for the class of motor considered, cannot exceed a value of 4·0, and may be anything between 1 and 4 (see later).

To be safe, let us take a value of 1·5, and we get :—

$$\text{Revised Interest, etc., Charge} = \frac{1{\cdot}81}{1{\cdot}5}\text{d.} = 1{\cdot}21\text{d. per unit.}$$

Estimating the remaining items as for the motor of Class I., and remembering that our new load factor is 11 per cent ($= 7\frac{1}{2}\,\% \times$ Diversity Factor), we obtain the following approximate figures :—

Management, Salaries, and Office $=$ 0·104d. $+$ 0·138d. $=$ 0·242d. per unit.
Rates, Taxes, etc. $=$ 0·060d. $+$ 0·013d. $=$ 0·073d. per unit.
Net profit $=$ 0·37d. $\times \frac{15}{11} =$ 0·44d. per unit.
Works cost $=$ say 0·95d. per unit (on account of increased stand-by charges).
Total cost $=$ 1·21d. $+$ 0·242d. $+$ 0·073d. $+$ 0·44d. $+$ 0·95d. $=$ 2·91d. per unit.

The above is for the case of a consumption of 162 units per H.P. installed, per quarter ; corresponding to an average of one-fourth of the H.P. installed during the nine working hours of the day. (In Bradford the average consumption per H.P. installed per quarter was 110, and in Leeds 200, units per quarter during 1902.)

It will be noticed that in the above case the estimate is considerably above the 2d. per unit which was suggested earlier in this paper ; but, on the other hand, the diversity factor might easily run up to 2 in certain towns, which would improve the "station" load factor and so reduce charges all round, as well as reduce the works cost. The "motor" load factor (see later) would remain constant at $7\frac{1}{2}$ per cent. taken over the year.

"Non-interest-paying" Motor Load.—The author desires, in the present paper, to emphasise the suggestion that it would seem to be impossible in ordinary electric lighting stations worked under municipal conditions (*i.e.*, limited in size by the size of the town whose needs they supply) to offer the supply of power during the day time at rates below 1d. per unit on a sound financial basis, except subject to certain restrictions.

Referring to the motors typified under cases Nos. 1 and 2, it

* "Productive Capital" only (see later in this paper).

will be seen that, apart from interest charges, the respective costs would be only 1·0d. and 1·7d. per unit. And there is no doubt in the author's mind, that if an electric light station of the above class were to start charging rates as low as these, the regulation amounts for interest and sinking fund and the usual "net profits" would still be maintained for the first four or five or more years (as will be shown later in this paper), and a fine motor business would be built up. After the fourth or fifth year, however—the actual time depending on the normal rate of growth of the lighting business—it would be found that "extensions" in plant and mains begin to be required very rapidly, and the price for motive power would then have to be raised. The safer course is to be found, it seems to the author, in offering these rates subject to such stipulations as shall protect the scheme from financial unsoundness.

Briefly the stipulation to be made is that the consumer shall enter into an agreement with the Supply Company, or the Corporation, to take no current for motive power purposes between certain hours during the winter months, in return for these extremely low rates, subject to the penalty of being put on a 2-rate meter combined with a time-switch in the event of the offence being persisted in. The Company's or Corporation's inspector to have the right to enter premises without notice (as he has now) for purposes of ascertaining compliance with conditions.

The hours at which current would be cut off would be as follows:— September, 5.30 p.m.; October, 4.30 p.m.; November, 3.30 p.m.; December, 3.0 p.m.; January, 3.30 p.m.; February, 4.30 p.m.; March 5.30 p.m.

It may be said that such conditions will deter any one from taking current for motors. There are two obvious answers to this, viz., (1) that if this is so, there can at least be no risk, in offering these conditions, of the station being swamped with a motor load which might exceed even its "midday" capacity; (2) the station must, at least, better its present motor load, for it is inconceivable that, in any industrial town of moderate size, there shall not be *some* consumers who could afford to have their power cut off at certain hours in the winter.

That the system is not altogether impracticable is proved by the fact that, at Montreal, 30 per cent. of the motor H.P., which the author understands amounts to 18,000 k.w. (though on this point he is waiting for corroboration from Montreal), is so connected.

Also at Brighton, in this country, some 750,000 units are annually sold on these terms; and the author is informed, on reliable authority, that at another town in this country a large contract for the sale of something like three million units per annum, on a ten years' basis, is now under negotiation, at exceptionally low rates, for the supply to the works of a single large manufacturing firm, on the above basis.

When it is remembered that the whole motive power output at Bradford in 1903 was only a little over two million units, the importance of the above will be appreciated.

Limit of Station Plant dependent on Day Fogs.—This raises a question on the other side: "If the development is likely to be so rapid, what is to protect the lighting load from extinction in the event of a day fog?" This difficulty is not so easily met, but a reference to Fig. 1 shows that, where the lighting load undergoes steady development year by year—10 per cent. is here assumed—and the motor load starts from small beginnings, as in the vast majority of lighting stations at the present time, it takes several years for the motor load to overtake the lighting load to such an extent as to imperil the lighting in the event of a day fog. The author does not speak at random when he states that in most large towns, except perhaps London and one or two others, it will be found that the worst day fog never gives a demand, for lighting alone, greater than 66 per cent. of the worst "peak" of the following December. In Fig. 1 this is taken as a basis, and it is found that 1,700 kilowatts of motor load, representing about 5,500,000 units per annum, can be added to the output of a station whose initial "peak" is only 1,800 kilowatts, before the limit of the capacity of the plant to deal with a day fog is reached. This assumes a 60 per cent. motor load development annually for five years—very nearly equal to the magnificent results obtained at Bradford between 1896 and 1901. If such an extremely rapid motor load should *not* be realised, owing to the restrictive conditions, the period of development will be longer before the limit is reached, and the limit itself will also be raised in consequence.

Fig. 2 shows the same principle applied to a lighting load which refuses to be developed. Here the limit is reached in four years, for the same rate of motor load development as before. The annual motor units thus added are in this case only 3,360,000, and the kilowatts are 1,060.

But most engineers will concede that a 10 per cent. annual growth in the lighting demand alone is not at all an exaggerated estimate of probabilities. Hence we may reckon upon the five and a half million units of Fig. 1; for the rate of growth of the *motor* load is certainly not *under*-estimated, but probably the reverse.

Assistance from Traction Plant.—Where there is a traction load, as well as a lighting load, supplied from the one station, it will be readily seen that the above limit will be considerably extended.

The traction load will develop annually by a given amount, and plant will be put down to meet it. Now, the maximum traction demand will never be likely to occur at the time when the "day fog" load is at its maximum, for the workmen and employés, who constitute a large part of the traction load, cannot be in their factories, shops, and offices at the same time as they are on the cars; hence there should be fully from 10 to 20 per cent. of the traction plant available for the fog peak at such a time, without drawing at all upon the overload capacity of the said plant. The lighting mains would, however, in such a case be overloaded.

Taking all things into consideration, the author feels safe in suggesting that the risk in offering to consumers their power free of

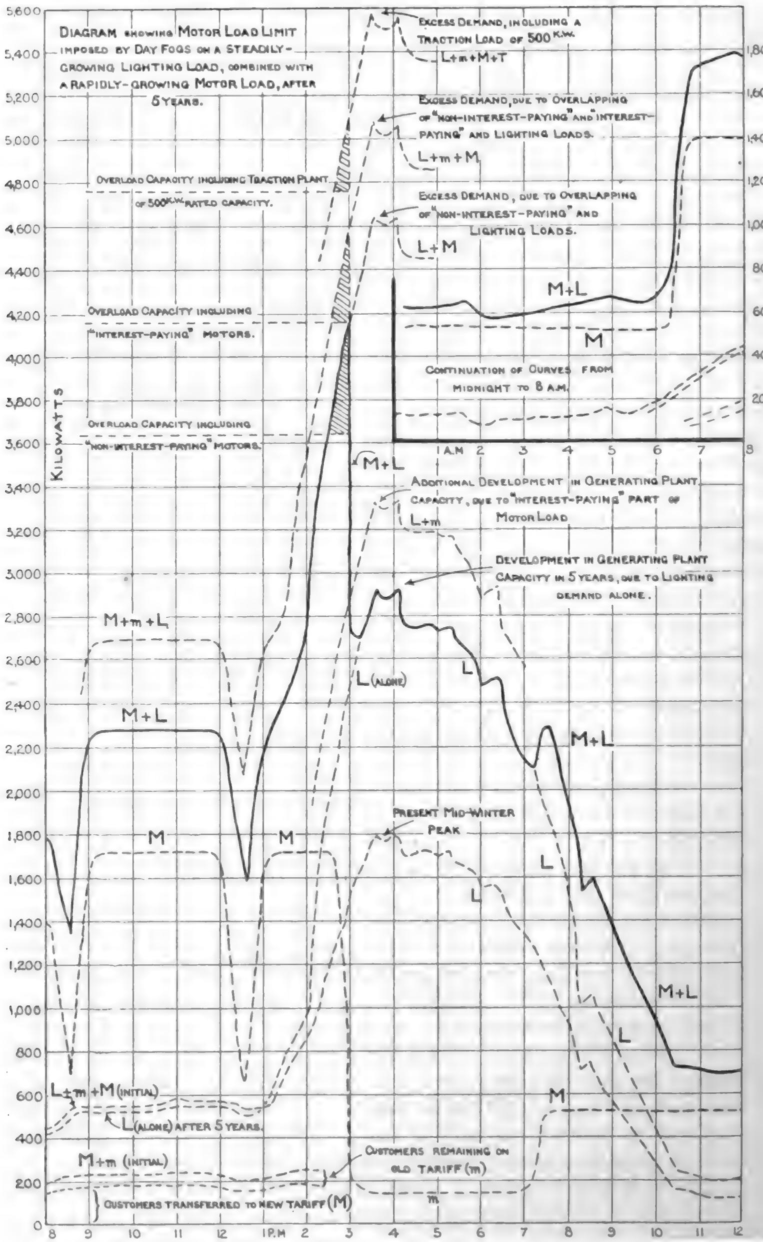


DIAGRAM SHOWING MOTOR LOAD LIMIT IMPOSED BY DAY FOGS ON A STEADILY-GROWING LIGHTING LOAD, COMBINED WITH A RAPIDLY-GROWING MOTOR LOAD, AFTER 5 YEARS.
KILOWATTS
EXCESS DEMAND, INCLUDING A TRACTION LOAD OF 500 K.W.
L+m+M+T
EXCESS DEMAND, DUE TO OVERLAPPING OF "NON-INTEREST-PAYING" AND "INTEREST-PAYING" AND LIGHTING LOADS.
L+m+M
OVERLOAD CAPACITY INCLUDING TRACTION PLANT OF 500 K.W. RATED CAPACITY.
EXCESS DEMAND, DUE TO OVERLAPPING OF "NON-INTEREST-PAYING" AND LIGHTING LOADS.
L+M
M+L
M
OVERLOAD CAPACITY INCLUDING "INTEREST-PAYING" MOTORS.
CONTINUATION OF CURVES FROM MIDNIGHT TO 8 A.M.
OVERLOAD CAPACITY INCLUDING "NON-INTEREST-PAYING" MOTORS.
ADDITIONAL DEVELOPMENT IN GENERATING PLANT CAPACITY, DUE TO "INTEREST-PAYING" PART OF MOTOR LOAD
L+m
DEVELOPMENT IN GENERATING PLANT CAPACITY IN 5 YEARS, DUE TO LIGHTING DEMAND ALONE.
M+m+L
L (ALONE)
L
M+L
PRESENT MID-WINTER PEAK
L+m+M (INITIAL)
L (ALONE) AFTER 5 YEARS.
M+m (INITIAL)
CUSTOMERS REMAINING ON OLD TARIFF (m)
CUSTOMERS TRANSFERRED TO NEW TARIFF (M)
m
5,600
5,400
5,200
5,000
4,800
4,600
4,400
4,200
4,000
3,800
3,600
3,400
3,200
3,000
2,800
2,600
2,400
2,200
2,000
1,800
1,600
1,400
1,200
1,000
800
600
400
200
0
8 9 10 11 12 1 P.M. 2 3 4 5 6 7 8 9 10 11 12
1 A.M. 2 3 4 5 6 7 8

FIG. 1.

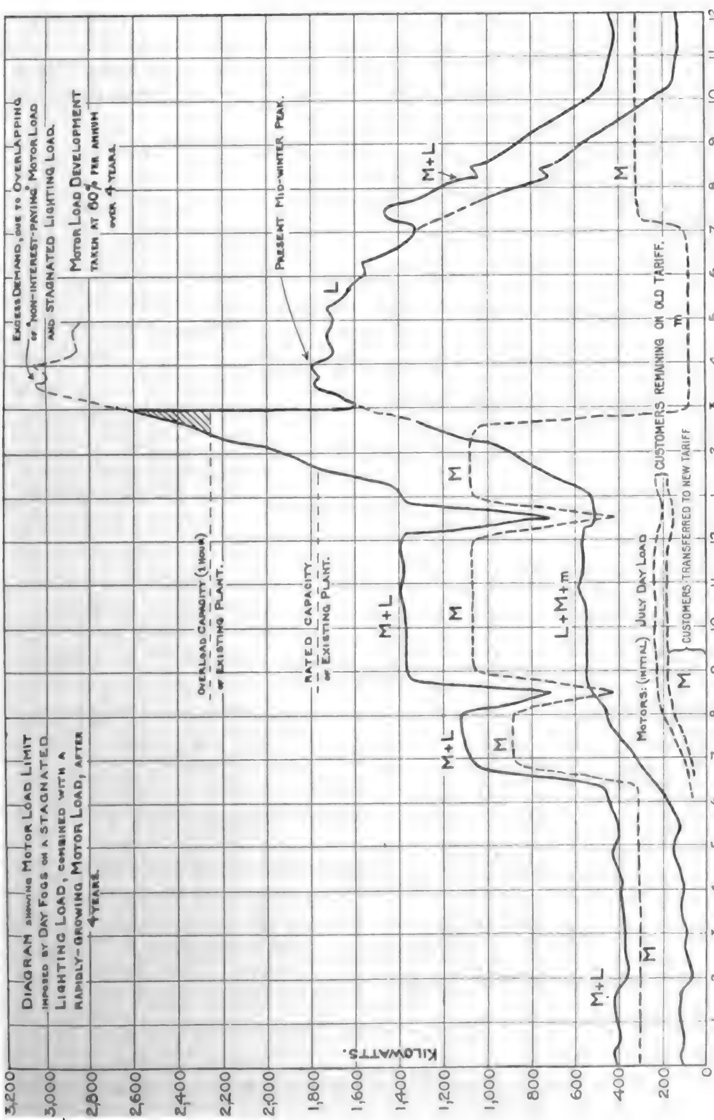


DIAGRAM showing MOTOR LOAD LIMIT imposed by DAY FOGS on a STAGNATED LIGHTING LOAD, combined with a RAPIDLY-GROWING MOTOR LOAD, after 4 YEARS.
KILOWATTS.
OVERLOAD CAPACITY (1 HOUR) of EXISTING PLANT.
RATED CAPACITY of EXISTING PLANT.
PRESENT MID-WINTER PEAK.
EXCESS DEMAND, due to OVERLAPPING of 'NON-INTEREST-PAYING' MOTOR LOAD AND STAGNATED LIGHTING LOAD.
MOTOR LOAD DEVELOPMENT TAKEN AT 80% PER ANNUM OVER 4 YEARS.
MOTORS: (INITIAL) JULY DAY LOAD
CUSTOMERS REMAINING ON OLD TARIFF.
CUSTOMERS TRANSFERRED TO NEW TARIFF
M+L
M
L
L+M+m
m

FIG. 2.

interest charges, but subject to the "excepted hours" condition, is a very slight one even where there is no traction load, and it is still less where there is. In any case, the basis is a more sound one than it at present is in some stations, as the daily overloading of the plant would be avoided.

It may, at this point, be worth while putting the question: "What is the manufacturer to gain by accepting such an offer as has been

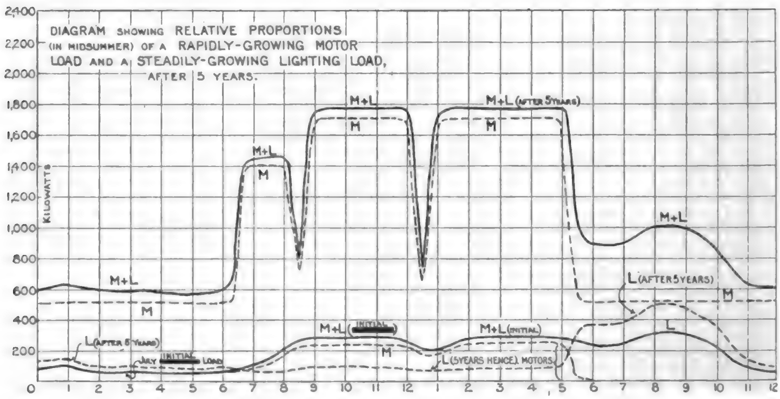


FIG. 3.

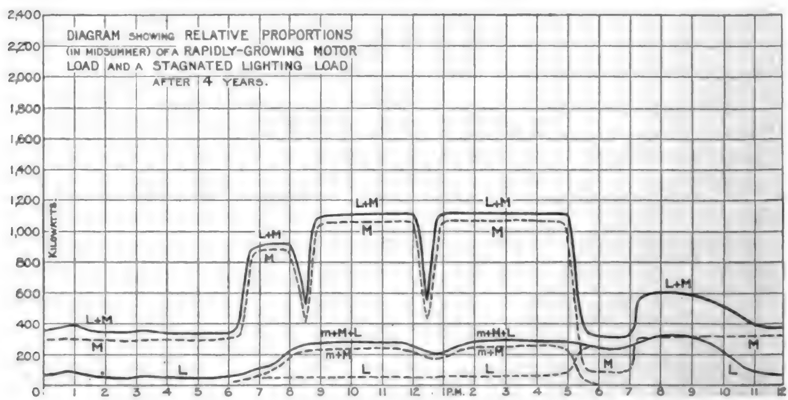


FIG. 4.

indicated?" In these days of high pressure, could he possibly spare those two hours every day? He is to obtain a reduction in price from, say, 1·5d., to, say, 0·5d. per unit, available all night as well as all day with the exception of two, or at most three, hours. If, then, he is working his machinery to anything like the same extent by night as he is by day, he gets considerably over 100 per cent. more horse-power hours

for the same sum that he would have paid under existing conditions. But not only that; for if a moderate number of such contracts were reasonably likely to be secured in one town, they would bring in their train additional "interest-paying" motor customers and lighting customers, and the station, being larger, could afford to give better terms still, as the works "production" costs would be less.

The customer is, in fact, saved the capital cost, and bother, of his own generating plant, while securing nearly all its advantages. It seems to be generally recognised that private installations of moderate size cannot provide their own motive power at less than ½d. to ¾d. per B.H.P. per hour, which corresponds to electricity at 0·7d. to 0·9d. per unit. (J. F. C. Snell, on "Distribution of Electrical Energy," *Proceedings of the Institution of Civil Engineers*, 1904; also discussion on Mr. Earle's paper on "Supply of Electricity in Bulk," *Journal of the Institution of Electrical Engineers*, vol. 31, p. 917.

In this connection, Mr. Clirehugh's remarks at the discussion on Mr. Earle's paper are of interest: "Their (Trafford Park) consumers frequently ran machines, which were busy, for two shifts a day; a thing which would be uneconomical if they had to keep an engine and boiler running to drive them." The average price at Trafford Park is given by the same speaker at 1·1 pence per unit.

Suggestion for meeting Consumers who object to the "Excepted-Hour" Conditions.—In those cases in which it is imperative to consumers to have the supply at all hours, it would seem practicable to offer some such arrangement as the following:—

Coupled to the consumer's motor would be a small dynamo of very low voltage, shunt wound and connected up with, say, half a dozen or a dozen cells of moderate size. During the day the motor, which would normally be working at, say, one-half to one-fourth of its full power, could spare power to drive the dynamo to charge the cells at a low rate. As the time of evening peak load drew near, a time switch in the 500-volt motor circuit would first insert resistance into the field of the dynamo; then, as the latter began to act as motor, driven from the cells, the switch would open the circuit of the 500-volt motor and not close again till, say, 5 p.m. It would also be practicable to arrange the time switch to be controlled by current traversing lamps which were certain to be lighted during a fog peak; so that the 500-volt motor was disconnected from the mains while the fog was on.

This would relieve the generating station of any demand on account of fog peaks for those consumers who had the arrangement installed; and would, to that extent, extend the motor load development limit of the station indefinitely.

The special dynamo, the battery, and accessories, could be easily installed and maintained free of charge either by an intermediary company, or by the Corporation. The author estimates that only some 0·3d. to 0·35d. would be necessary to be charged additional on each unit sold, to pay for and maintain the dynamo and battery, in the case of a 10-H.P. motor working on the average at half its rated load. If the consumer bought his own battery and dynamo, the maintenance

of the battery would only cost him about 0·075d. per unit. The battery for a 5-H.P. motor would occupy a floor space no greater than is usually occupied by a bicycle, and should be easily accommodated in the basement of a building. This suggestion has the advantage over what would, at first sight, appear to be the most obvious course (viz., to put the battery at the central station), in that any battery put down at the station would not save the *mains* from having to be extended. Where the motors would be of over 15 H.P., the cells would be put in for the full E.M.F. of the supply, and a booster used in place of a dynamo.

Reduction in Works Cost to secure "Non-interest-paying" Motor Load.—Hitherto in this paper it has been assumed that it was correct to charge the motor load with the full present value of the "Works Cost." Such a course, however, the author believes to be quite unnecessary.

The charge on account of Wages may be almost entirely dropped—may, at any rate, be safely reduced to, say, quite 25 per cent. of its present cost in any station about to make the change in its policy. This item, in stations of about 2,000 kilowatts capacity, is frequently of the order of 0·2d. per unit, especially where there is no traction load. This might be reduced to 0·05d. per unit. The item of repairs Mr. Arthur Wright (see *Electrician*, Dec. 27, 1901) considers is capable of division into "production" and "preparation" charges in the ratio of 1 to 3 in the case of Brighton. Let us be content to take a ratio of 1 to 2 as being safer. A figure frequently obtained for this item is 0·2d. per unit; let us then take 0·10d. per unit. Oil and stores we may put at 0·05d. per unit.

We now come to the coal bill. Mr. Arthur Wright, in his very interesting and valuable paper read before this Institution in 1901, represents the monthly costs plotted against sales by a diagram (Fig. 5), which I have modified to suit another station, and in which you will find bracketed a monthly sum representing the average "production cost" for coal alone obtained on Mr. Wright's system, for an average month's output.

Suppose now that the station were to take up a motor load of an average number of units monthly equal to an average month's lighting output; we can then draw a line parallel to the upper boundary of the diagram and at a height above it equivalent to the average monthly cost of "production," including proportions of repairs, oil, and wages, and the area thus added (shaded and marked "Motors" in Fig. 5) will represent the additional total cost for six months.

Now the relative areas of these figures are as 1 to 1·75, and each corresponds with an equal number of units generated; hence the costs per unit are in the same ratio, and if the lighting cost had averaged 1d. per unit we should be justified in charging only 0·57d. per unit for the complete "works cost" of the motor load.

It is of course plain that the relative areas of the two figures depend very greatly—in fact, if we take repairs, wages, and oil as constant values, as has been done in this diagram, they will depend *entirely*—on

the "Stand-by Losses" of the station; and in a station, for example, that has a traction load the "Motor" cost would bear a larger proportion to the existing works cost. The diagram is, however, given to illustrate the principle, and must not be taken as representative unless for a station that has nothing but a lighting load.

As indicated above, it will be seen that if the items for wages, repairs, and oil be omitted from the above diagram, the actual sum bracketed remains true for the coal alone for the motor load, and the ratio between this and the average total cost for coal would, in the case taken, be as $\frac{1}{1 \cdot 5}$. Hence, if the station had been costing 0·45d. per unit for coal with the lighting load alone, we could assess the coal item at 0·3d. for

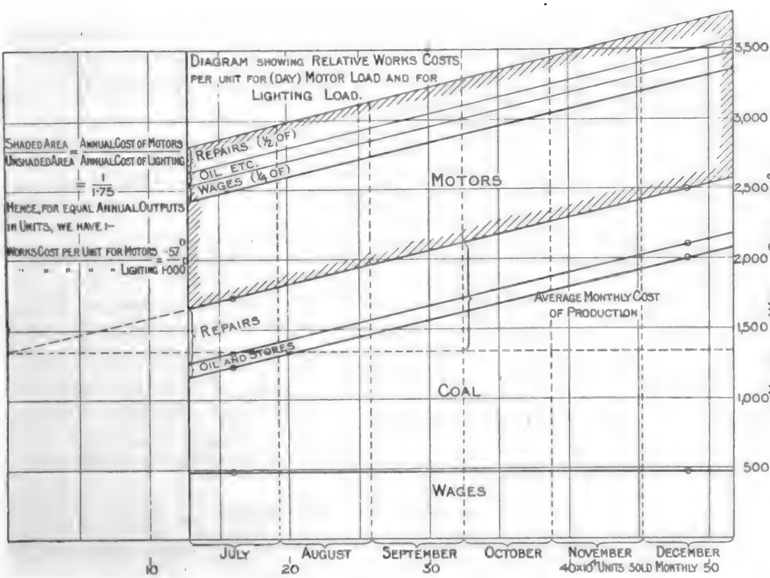


FIG. 5.

the motor load. This the author considers the better way of estimating this item.

Summing up the items for the works cost we thus have: Wages = 0·05d.; repairs = 0·12d.; oil and stores = 0·03d.; coal = 0·3d. Total Works Cost = 0·5d.

Add to this, for the least favourable class of consumer, as follows: Office expenses = 0·104d.; rates, rent, taxes = 0·013d.; net profit, 0·15d.; and we have:

Total charge to (non-interest-paying) consumer = 0·5d. + 0·27d. = *0·77d. per unit.*

Similarly treating the charges under Class I., we obtain the figure of 0·45d. for the works cost, and the inclusive figure of 0·54 per unit for the charge to the consumer.

The details of the figures for "works cost" are given in Table "B"; those for "selling price" in Table "A."

(See end of paper for Table B.)

As engineers may possibly be sceptical as to whether the deductions from Wright's diagram are really a safe basis on which to work in taking so important a step as the reduction of accepted lowest prices by over 40 per cent. in a comparatively small station of only 2,000 kilowatts capacity, the author has attempted to verify this by a different method. By means of the diagram shown in Fig. 7, a description of which follows later in this paper, he has calculated the monthly coal consumption for the curves shown on Figs. 4 and 2, representing respectively an average day in July and in December. The results are given in the Tables of Coal Consumption at the end of the paper. By the aid of these tables the "coal" item of Wright's diagram can be reconstructed, and the average monthly "production cost" obtained. The results prove the deductions made above to be reliable.

Summary of Results: Actual and Possible Selling Prices Compared.

It will now be convenient to summarise, in a tabular form, the results which have been obtained thus far.

Referring to Table "A," in the first column the author gives average results obtained with stations of about 2,000 kilowatts capacity, having no traction load. The items have mostly already been alluded to, but it should be remarked that the interest charge on what the author calls "Unproductive" capital (see Fig. 9, later) is entirely omitted. This is the cause of the low selling price, viz., 2·94d. per unit; which, however, includes interest on £70 for every kilowatt of station output.

In the second and fourth columns are tabulated the results already obtained for motors of Classes I. and II.; as to which no further explanation seems necessary, except to emphasise the point that no other load on the station than the motors is considered, and that night loads are not assumed.

In the third and fifth columns, a "day" load on the "restricted-hours" principle is assumed to be taken up by an already-existent 2,000 k.w. lighting station, in the manner indicated in Fig. 1 of the paper. No additional generating plant has to be put down; hence those items of charge analysed in some detail under Class I. Motor are only in part debitable to the new load. For example, no material addition to the management and technical staff will be necessary, though it will be to the office staff, hence the former item is dropped (being already borne by the lighting) while the latter is retained.

Again, the Assessment of the station will probably remain unaltered, so long as no additional capital is spent on the station, and the "non-interest-paying" load is not looked to as a material source of profit in itself, but rather as a means of bringing in "interest-paying" motors

TABLE A.

Summary of Results :—Actual, and Possible, Selling Prices.

	Electric Lighting only. — Average of several Stations of 2,000 Kilowatts and under.	Motors of Class I. — Station Load Factor = 30 %. — Diversity Factor = 1. — Maximum Load = 2,000 k.w.	Ditto on "Restricted Hours" System. — Station Load Factor = 55 %. (40 % Motors. 15 % Lighting.) — Small Night Load, as per Fig. 1.	Motors of Class II. — Station Load Factor = 11 %. (7½ % × 1·5 D.F.) — Diversity Factor = 1·5. — Maximum Load = 2,000 k.w.	Ditto on "Restricted Hours" System. — Station Load Factor = 25 %. (10 % Motors. 15 % Lighting.) — Small Night Load, as per Fig 1.	Motors of Class I. — Station Load Factor = 30 %. — Diversity Factor = 1. — Maximum Load = 10,000 k.w.
	d.	d.	d.	d.	d.	d.
"Works Cost"	1·20	0·70	0·45 †	0·95	0·50 ‡	0·40
Interest and Sinking Fund at 7 % on "Productive Capital" only*	1·00	0·45	Nil	1·21	Nil	0·32
Management, Salaries, and Office	0·23 (0·115 + 0·115)	0·079 (0·022 + 0·057)	0·022	0·242 (0·104 + 0·138)	0·104	0·039 (0·022 + 0·017)
Rates, Taxes, etc.	0·14 (0·12 + 0·02)	0·040 (0·030 + 0·010)	0·010	0·073 (0·060 + 0·013)	0·013	0·033 (0·025 + 0·008)
Net Profit	0·37	0·18	0·06	0·44	0·15	0·14
Selling Price	2·94	1·45	0·54	2·91	0·77	0·93

* See Fig. 9. † Reduced from 0·7d. by subtracting "Stand-by Losses." ‡ Reduced from 0·95d. by subtracting "Stand-by Losses."

and lights in its train. The first part of the "Rates, etc." item has therefore been dropped, and only the second inserted. For the same reason, and for the additional one that, if the offer meets with anything like the response which the station is capable of dealing with (see notes in connection with Fig. 1), the load factor of that part of the station load which belongs to the motors would be of

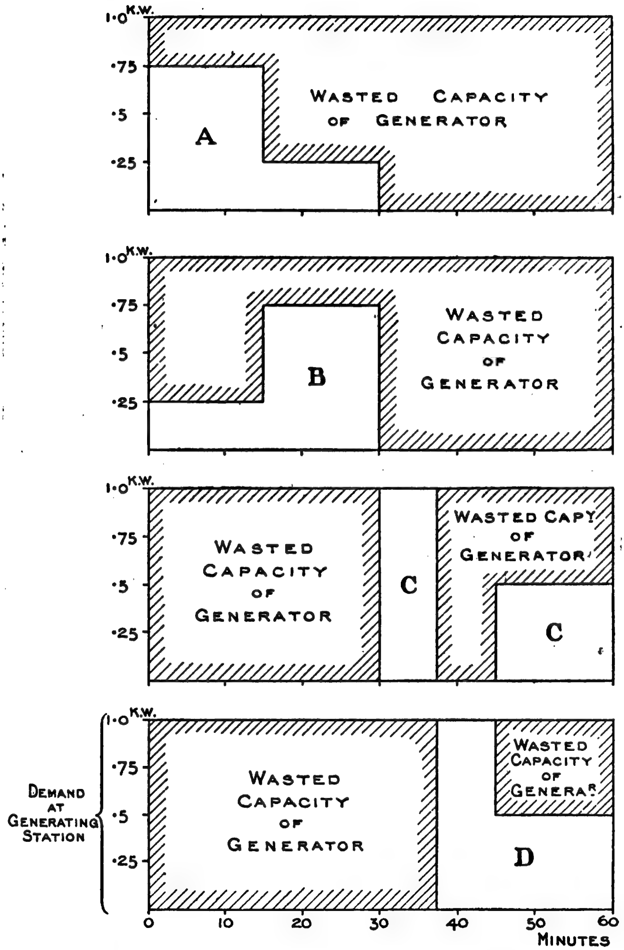


Fig. 6.—Diagram showing relation of Load Factor and Diversity Factor for Motors of Class II. under the most favourable conditions.

Motor Load Factor (during 1 hour cycle) = 25 %.
Motor Diversity Factor (during 1 hour cycle) = 4.
Station Load Factor (during 1 hour cycle) = 100 %.
" " " (" year) = 30 %.
Motor " " (" ") = $7\frac{1}{2}$ %.

the order of some 40 per cent., the item for "net profit" has been reduced to 0·06d. per unit. Even at this small figure, it would represent nearly £1,400 per annum on 5,500,000 units.

The item for "works cost" is reduced to 0·45d. from 0·70d., eliminating all "stand-by" charges, which are supposed to be already borne by the charge made on account of lighting.

Needless to say, even better results (down to 0·45d. per unit for

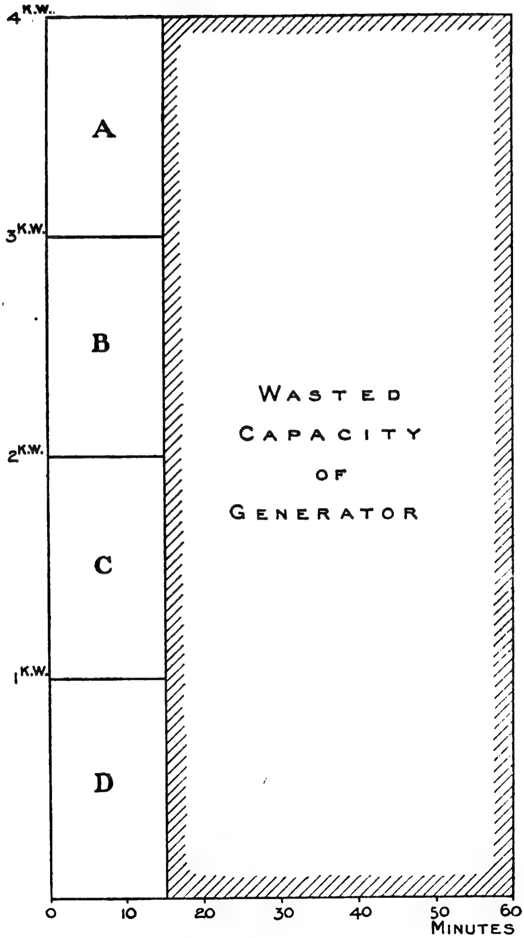


FIG. 6A.—Diagram showing relation of Load Factor and Diversity Factor for Motors of Class II. under the least favourable conditions.

Motor Load Factor (during 1 hour cycle) = 25 %.
Motor Diversity Factor (during 1 hour cycle) = 1.
Station Load Factor (during 1 hour cycle) = 25 %.
" " " (" year) = $7\frac{1}{2}$ %.
Motor " " (" ") = $7\frac{1}{2}$ %.

Class I.) would follow if a large motive power load could be obtained for the night, as might be quite possible where the driving of manufacturers' works could be taken up seriously and at prices which defied competition from their own plant.

Before passing from the discussion of Table "A," it should be remarked that the last column is compiled in the manner indicated in paragraph headed "Effect of Size of Station, etc." (see Appendix).

Diversity Factor.—A word or two in explanation of the figure of 1·5 assumed for the probable value of the diversity factor, in motors of Class II., may here be desirable.

The motor considered is one that runs for 4½ hours per day with a varying load averaging *one-half* the motor H.P. installed, and during the other 4½ hours is standing still or running empty. Consider four separate motors of this class. A. runs his motor at ¾ of its full load from, say, 11.0 a.m. to 11.15 a.m., and at ¼ of its full load from 11.15 to 11.30 a.m. B. does the reverse with his motor. C.'s motor is entirely off (or running empty) during this period; as also is D.'s motor.

At 11.30 a.m. A.'s and B.'s motors both have their loads taken off and C.'s motor starts at *full* load and runs thus until 11.37 a.m. C. now switches off his load and D. starts his motor at *full* load and runs till 11.45 a.m. From that time till 12 noon, both C. and D. are running their motors at half their full load.

These conditions are shown by Fig. 6.

It will be evident that the four motors entirely fill up the area of the diagram represented by 1·0 kilowatt for one hour at the generating station. That is, four motors, each having a maximum output of 1·0 H.P. can, in the limit, be run off every kilowatt of (maximum) load at the generating station. Hence the diversity factor is, in the limit, = 4·0. But it is obvious that in practice the loads of these motors could not be prevented from overlapping to such an extent as to considerably exceed the 1 kilowatt assumed for the station's maximum output. If, for example, all four motors happened to clash, all fully loaded, we should require 4 kilowatts at the station instead of 1 k.w. This would only last for 15 minutes, the remaining ¾ hour being run at the station with empty generators.

This condition of things is shown by Fig 6A.

We may now summarise results, as follows:—

CLASS I.

"Motor" Load Factor (during 9-hour cycle)	=	100 per cent.
" Diversity Factor " "	=	1 "
Station Load Factor " "	=	100 "
" " " (during year)	=	30 "
Motor " " "	=	30 "

CLASS II.

Most Favourable Diversity Factor.

Motor Load Factor (during 9-hour cycle)	=	25 "
" Diversity Factor " "	=	4 "
Station Load Factor " "	=	100 "

Station Load Factor (during year)	=	30 per cent.
Motor „ „ „	=	$7\frac{1}{2}$ „

Least Favourable Diversity Factor.

Motor Load Factor (during 9-hour cycle)	=	25 „
„ Diversity Factor „ „	=	1 „
Station Load Factor „ „	=	25 „
„ „ „ (during year)	=	$7\frac{1}{2}$ „
Motor „ „ „	=	$7\frac{1}{2}$ „

In the case of Class II. Motor, the two limiting values of the diversity factor are, therefore, 1 and 4; hence 1·5 would seem to be a *safe* value to estimate upon, and is that adopted in the author's calculations.

Two interesting things are elicited from the above investigation: first, that the diversity factor is, in the limit, the reciprocal of the load factor of the motor, taken over the same cycle; secondly, that *the "station" load factor is obtained by multiplying the "motor" load factor by the diversity factor.*

Hence it would appear that the method of rating consumers on the load factor of their motors is not an entirely sound one, unless the diversity factor is also taken into account. In the absence of a recorder curve of the motor load, it is, however, almost impossible to say what is the real value of the diversity factor for any particular class of motor.

Where a motor is known to repeat its functions daily, why should not a portable instrument be temporarily inserted on the motor circuit and this curve obtained?

General "Stand-by Loss" Diagram.—It is likely that most engineers responsible for the running of stations have felt that if the whole of the losses which occur in the station, and those in substations in addition, from the putting in of the coal into the boilers to the delivery of current to the bus-bars, could be added together graphically, and if the relative effect which each has upon the general efficiency of the station under the varying conditions of load could be so shown, we should have a guide which would materially facilitate a comparison between the coal consumptions of stations whose lay-out, load factor, and plant differed considerably from one another.

The diagram shown in Fig. 7 is an attempt to represent the hourly rate of burning coal in terms of the kilowatts of output of that part of the load-curve of the station which may be under consideration. The principle of the diagram is as follows:—Starting with D.C. kilowatts at bus-bars, plot a curve connecting this with indicated H.P., and a little below this curve plot another curve, nearly parallel to it, connecting kilowatts with electrical H.P. The space enclosed between these two curves will then obviously represent the combined electrical and mechanical losses of the generator for different proportions of its load. (See also Appendix.)

Next, use the I.H.P. scale as the scale of abscissæ, and for the scale of ordinates take pounds of steam delivered by the boiler per hour to

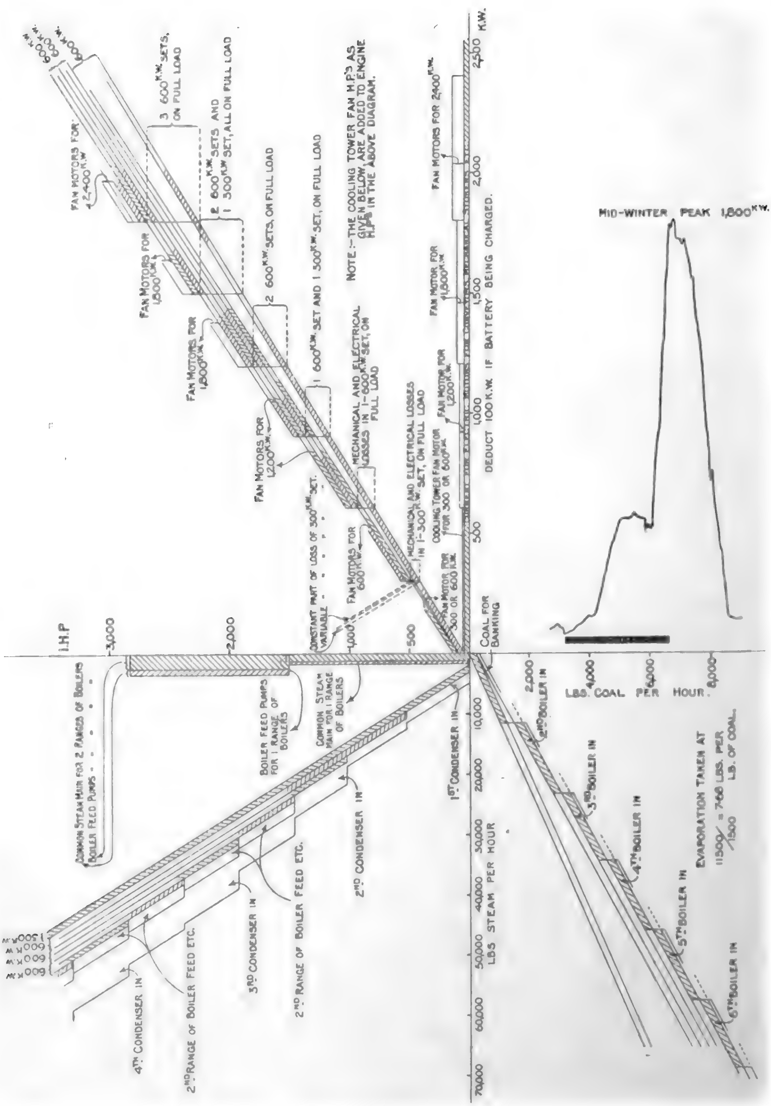


Fig. 7.

the main steam range. Plot first a curve connecting steam consumed by the engine with I.H.P.; then draw above this (in Fig. 7 it is shown at foot) a line representing excess steam necessary on account of steam feed-pumps, then a line above this (also shown at foot in Fig. 7) representing condensation losses in steam pipes to boiler and engine and in main steam range, then again a line above this representing steam consumed by the air and circulating pump engines.

Lastly, take the scale of pounds of steam per hour and use it as a scale of abscissæ and set off a scale of pounds of coal per hour as ordinates, and draw a curve connecting these. To settle what scale to employ for the total pounds of coal per hour, it must first be decided what evaporation to allow per pound of coal at full load of the boiler. The author has taken a figure of 7·68 lbs. for feed, as received from economiser, to pressure at say 160 lbs.; but this is a figure which each

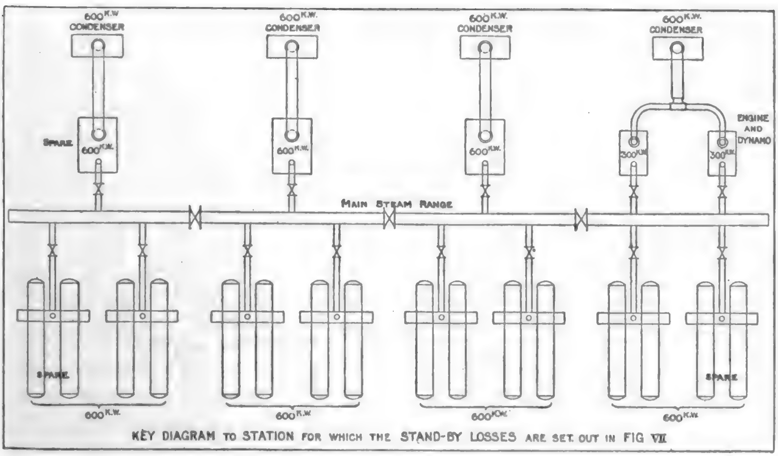


FIG. 8.

engineer must determine for himself, as it of course depends on the coal used and the economiser and boiler efficiency.

We now have a combination of three diagrams, and starting with any output in kilowatts, we can readily trace round through the three diagrams to the coal consumption per hour. We can also see the exact effect of "stand-by losses" in engines, dynamos, pipework, condensers, feed-pumps, boilers, etc. The diagram is constructed for a station the key to which is given in Fig. 8. Suppose, now, that we had no battery in the station, and that, at a certain hour of the night, we had only a few amperes leaving the station—fortunately an unpractical condition—requiring, however, that at least one boiler be kept under full steam and one dynamo maintaining bus-bar pressure, we find from the diagram that the stand-by losses are:—I.H.P. = 120; steam per hour = 6,000 lbs.; coal per hour = 900 lbs. This is for a boiler whose characteristic curve is given on Fig. 10 (labelled "St. Pancras test"),

and an engine of 375 kilowatts, triple expansion, by W. H. Allen & Co.

The author does not put forward any of the figures in Diagram 7 as final. He suggests that each station engineer may construct two diagrams, Figs. 7 and 8, to suit his own plant, and obtain from the engine, boiler, and pump makers curves for the apparatus they supply. If he then combines these and finds that the pounds of coal per hour, taken for any convenient part of his load curve whatsoever, differ materially from that which he is really burning, he will be justified in making a search to know the reason why. It is here that the diagram will help him, for there are certain losses in it which must be substantially correct, or their cause would be easily detected. Again there are others, such as steam-pipe radiation, which cannot be materially different from the plotted values; others, again, whose values, of themselves, are too insignificant to account for his discrepancies, and so on.

Lighting and Power Combined Development.—Another direction in which, it seems to the author, the electric supply has not been, in most cases, developed for all it was worth, lies in the fact that many of the supply concerns in this country have, from some cause or another—whether, through an unforeseen development of the demand, the site of the station has had to be shifted, or whether the mains necessary for one part of the town have been over-estimated, or whether the plant has been purchased at a premium, or whether the plant is obsolete and hence more costly than newer plant may be—whatever the cause may be, many of them have paid rather highly for their plant, and in this sense the system is burdened by what the author suggests may well be called "unproductive capital" charges. He would go further, and would express his definition of "unproductive capital" as follows: Any capital expenditure, whether in plant or in mains, which, if the station were started *de novo* at present prices (and with present plant overload capacities) and put down with only sufficient margin to carry it safely over the next year or two, might be avoided, is "unproductive capital."

If, for example, the feeders of a station are examined one by one at the time of the midwinter peak, and the currents traversing them and the distributors are noted and compared with the currents which they could carry if *all* loaded to say 90 per cent. of their full capacity, and if such proportion were found to be only 50 per cent., then one-half of the capital locked up in mains is unproductive. Again, if these same mains could be relaid, at present prices, for one-half of what they originally cost, no less than 75 per cent. of the capital on which interest has to be paid is unproductive.

The capital cost per kilowatt of maximum demand for both generating station (complete) and feeders may, for a station of 2,500 k.w., perhaps be put at about £70 per k.w., but there are hardly a dozen stations in the country that have reached this figure, and £140 and £150 per k.w. are quite common figures.

In Fig. 9 the author shows how that, *apart from* any reduction in

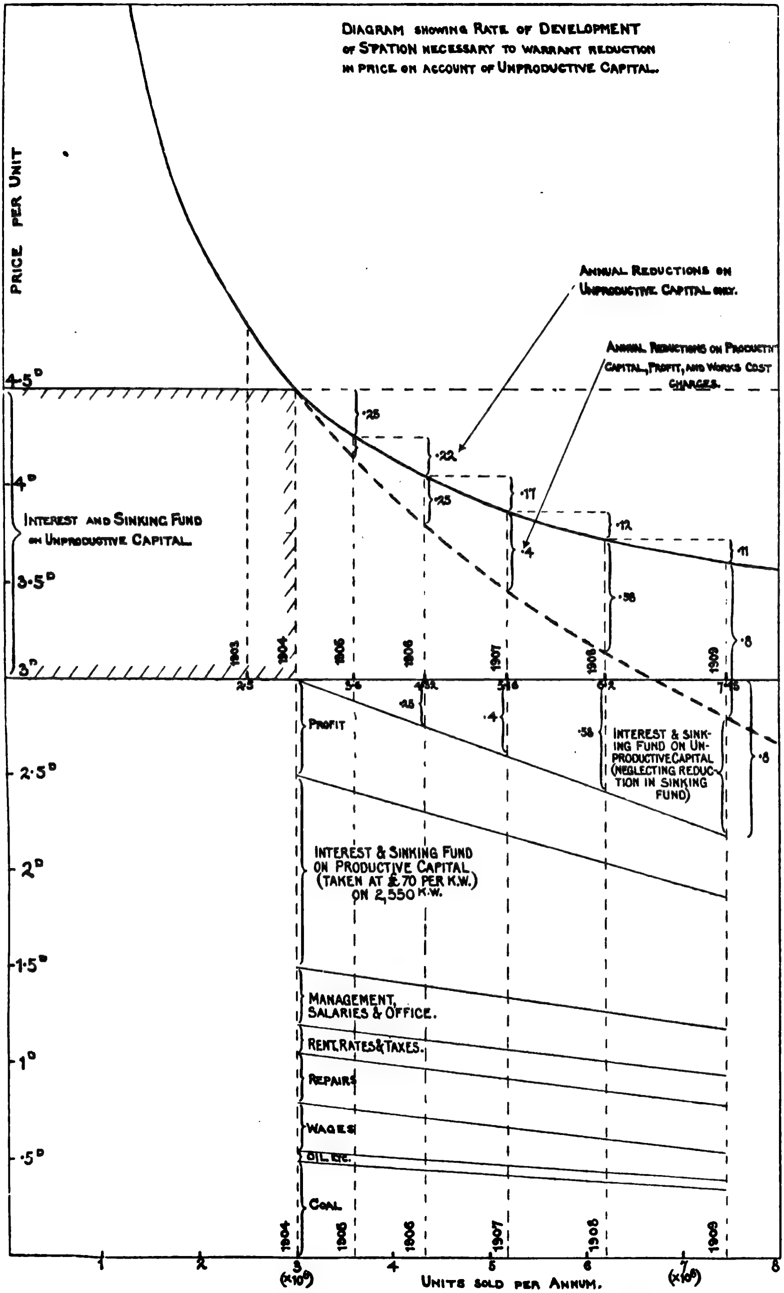


DIAGRAM SHOWING RATE OF DEVELOPMENT OF STATION NECESSARY TO WARRANT REDUCTION IN PRICE ON ACCOUNT OF UNPRODUCTIVE CAPITAL.
PRICE PER UNIT
ANNUAL REDUCTIONS ON UNPRODUCTIVE CAPITAL ONLY.
ANNUAL REDUCTIONS ON PRODUCTIVE CAPITAL, PROFIT, AND WORKS COST CHARGES.
INTEREST AND SINKING FUND ON UNPRODUCTIVE CAPITAL.
PROFIT
INTEREST & SINKING FUND ON UNPRODUCTIVE CAPITAL (NEGLECTING REDUCTION IN SINKING FUND)
INTEREST & SINKING FUND ON PRODUCTIVE CAPITAL (TAKEN AT £70 PER K.W.) ON 2,550 K.W.
MANAGEMENT, SALARIES & OFFICE.
RENT, RATES & TAXES.
REPAIRS
WAGES
OIL, ETC.
COAL
UNITS SOLD PER ANNUM.
(×10⁶)

Fig. 9.

"works costs" or total costs, one would be justified, in the case considered, in offering right away a reduction of 1d. per unit *if only* the demand would develop sufficiently rapidly in consequence thereof to compensate in a few years' time for the losses entailed during the first year or two. Fortunately, however, the case is not so improbable as would appear from a consideration of the "unproductive capital" item by itself. The costs of all the other items go down with increased output as, year by year, the improved prices produce their effect in getting more business; with the result that in Fig. 9 we could make an *annual* reduction in price of about $\frac{1}{6}$ penny during five years, or a total of nearly $1\frac{1}{2}$d. per unit, apart altogether from improvements in the economical working of the station which any capable engineer would be sure to effect in such a period.

The curve shown is based on a 15 per cent. lighting load increase and a 30 per cent. motor load increase, or a 20 per cent. combined increase in the sales during each year, a development which I believe I am right in saying has been well exceeded in several towns, notably at Bradford.

In view, then, of item (4) of the opening statement of this paper, would it not be expedient in the case considered in Fig. 9 to secure as many lighting and motor customers, on ordinary terms, at the present time by offering such a lump sum reduction as would recoup itself in, say, five years' time at the probable rate of growth of the combined load? The author throws out the suggestion for what it is worth, but it does seem to him that no stone should be left unturned to get hold of consumers *now*, for the same reasons that he has already urged in connection with a motor load.

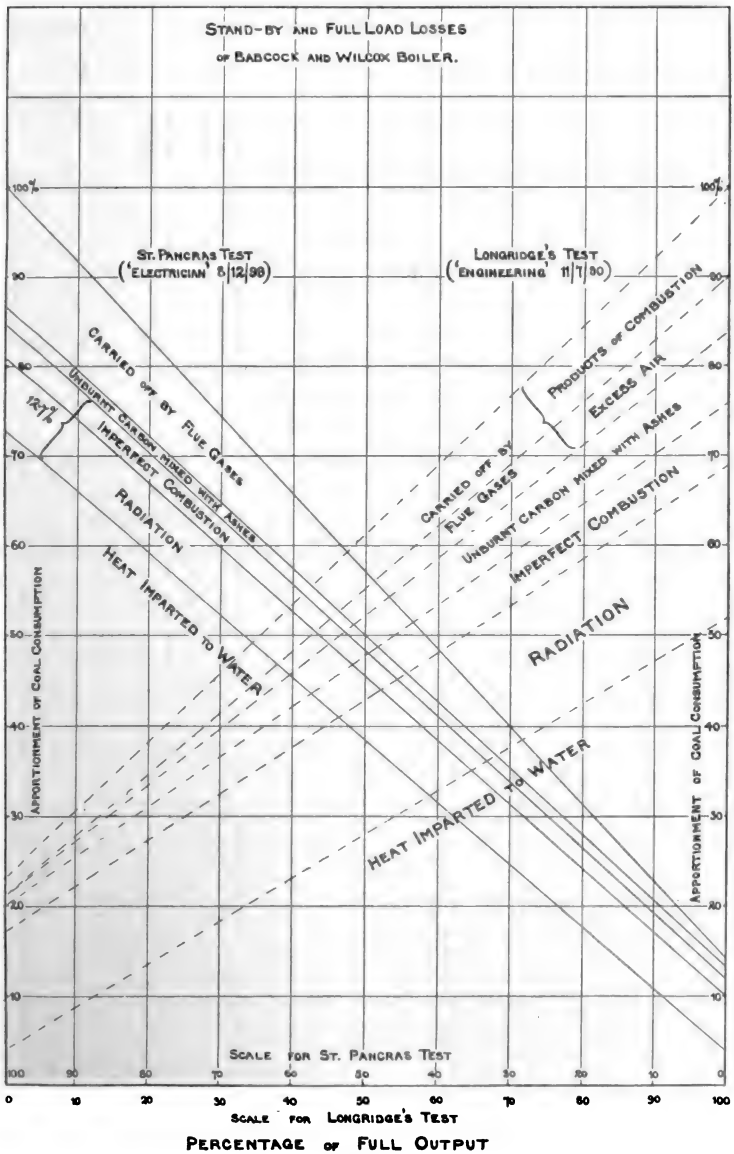
It is perhaps worth pointing out in this connection that if the author's suggestion for giving the "non-interest-paying" motor customers a means of tiding over the evening peaks and the occasional day fogs should prove to be practical, the same arrangement could be used to offer to lighting consumers a "non-interest paying" rate which, by comparison with present rates, would undoubtedly prove very attractive to those early-closing establishments who suffer under the "maximum demand" system in spite of the fact that it could not, from the nature of the case, be anything approaching the motor charge in cheapness.

CONCLUSIONS.

(1) In the case of lighting stations of 2,000 k.w. and under, it is not safe to offer current for motor supply, for day use, at anything below 1d. per unit except under the restrictions indicated, or where the lighting and motor loads do not clash.

(2) It is worth while *making* the offer to consumers of current at exceptionally low rates subject to these restrictions, no matter how greatly opinions may differ as to their being accepted.

(3) Such an offer it is in the capacity of any and every lighting station in the country to make immediately, without having to wait till they can lay down additional plant and mains;



Stand-by and Full Load Losses of Babcock and Wilcox Boiler.
St. Pancras Test ('Electrician' 8/12/98)
Longridge's Test ('Engineering' 11/7/90)
100%
90
80
70
60
50
40
30
20
10
12·7%
Carried off by Flue Gases
Unburnt Carbon mixed with Ashes
Imperfect Combustion
Radiation
Heat Imparted to Water
Products of Combustion
Excess Air
Carried off by Flue Gases
Unburnt Carbon mixed with Ashes
Imperfect Combustion
Radiation
Heat Imparted to Water
Apportionment of Coal Consumption
Scale for St. Pancras Test
100 90 80 70 60 50 40 30 20 10 0
0 10 20 30 40 50 60 70 80 90 100
Scale for Longridge's Test
Percentage of Full Output

Fig. 10.

COAL CONSUMPTION FOR JULY.

(Calculated.)

Peak and Evening Load (6–11 p.m.)				Day Load (6.30 a.m. to 6 p.m.)				Night Load (11 p.m. to 6.30 a.m.)			
Number and Capacity of Engines Running.	Number and Capacity of Boilers:— (R) = Running. (B) = Banked.	Hours of Running, Daily.	Coal per Month (Tons).	Number and Capacity of Engines Running.	Number and Capacity of Boilers:— (R) = Running. (B) = Banked.	Hours of Running, Daily.	Coal per Month (Tons).	Number and Capacity of Engines Running.	Number and Capacity of Boilers:— (R) = Running. (B) = Banked.	Hours of Running, Daily.	Coal per Month (Tons)
A.—*On Existing Output:—*											
K.W.		Hrs.	Tons.	K.W.		Hrs.	Tons.	K.W.		Hrs.	Tons.
1 × 300	1 R, 3 B	1	18·7	1 × 300	1 R, 3 B	2	33	1 × 300	1 R, 3 B	1	14·1
1 × 300	2 R, 2 B	3	64·2	1 × 300	1 R, 3 B	8½	170	1 × 300	1 R, 3 B	1	14·1
1 × 300	2 R, 2 B	1	17·9	1 × 300	1 R, 3 B	½	9·3	1 × 300	1 R, 3 B	1	14·1
				1 × 300	1 R, 3 B	½	9·3	1 × 300	1 R, 3 B	4	56·4
								1 × 300	1 R, 3 B	½	7
		Total	100·8			Total	218			Total	105·7

Combined Total = 412 Tons per Month.
Units Generated = 113,000 per Month.
Coal per Unit = 8·15 lbs.

B.—*With Increased Motor Load (4 years):—*											
K.W.		Hrs.	Tons.	K.W.		Hrs.	Tons.	K.W.		Hrs.	Tons.
1 × 300	2 R, 4 B	1	23·6	1 × 600, 1 × 300	3 R, 3 B	½	18·6	1 × 300	2 R, 4 B	1	24·8
1 × 600	2 R, 4 B	½	14·4	1 × 600, 1 × 300	3 R, 3 B	1	43	1 × 300	2 R, 4 B	1	24·8
1 × 600	2 R, 4 B	½	15	1 × 600, 1 × 300	3 R, 3 B	½	18·6	1 × 300	2 R, 4 B	1	24·8
1 × 600	2 R, 4 B	1	31·1	2 × 600	4 R, 2 B	½	28·1	1 × 300	2 R, 4 B	4	99·2
1 × 600	2 R, 4 B	1	31·1	2 × 600	4 R, 2 B	3	162	1 × 300	2 R, 4 B	½	12·4
1 × 600	2 R, 4 B	1	29·9	2 × 600	4 R, 2 B	½	28·1				
				2 × 600	4 R, 2 B	½	28·1				
				2 × 600	4 R, 2 B	4	216				
				1 × 600, 1 × 300	4 R, 2 B	½	22·7				
				1 × 300	2 R, 4 B	½	13				
		Total	145			Total	578			Total	186

Combined Total = 909 Tons per Month.
Units Generated = 425,000 per Month.
Coal per Unit = 4·79 lbs.

COAL CONSUMPTION FOR DECEMBER.

Peak and Evening Load (3-10.30 p.m.)				Day Load (6.30 a.m. to 3 p.m.)				Night Load (10.30 p.m. to 6.30 a.m.)			
Number and Capacity of Engines Running.	Number and Capacity of Boilers:— (R) = Running. (B) = Banked.	Hours of Running.	Coal per Month (Tons).	Number and Capacity of Engines Running.	Number and Capacity of Boilers:— (R) = Running. (B) = Banked.	Hours of Running.	Coal per Month (Tons).	Number and Capacity of Engines Running.	Number and Capacity of Boilers:— (R) = Running. (B) = Banked.	Hours of Running.	Coal per Month (Tons).
A.—*On Existing Output:—*											
K.W.		Hrs.	Tons.	K.W.		Hrs.	Tons.	K.W.		Hrs.	Tons
3×600	6 R 1 B	1	78·5	1×600	2 R 5 B	2	59	1×300	1 R 6 B	1½	28·2
3×600	6 R 1 B	2	157	1×600	2 R 5 B	4½	139	1×300	1 R 6 B	6½	114
2×600 1×300	5 R 2 B	2	133	1×600 1×300	5 R 2 B	1	44·5				
1×600 1×300	4 R 3 B	1	43	2×600 1×300	6 R 1 B	1	66				
1×600	2 R 5 B	1	27·3								
1×300	1 R 6 B	½	18·8								
		Total	457·5			Total	308·5			Total	142
Combined Total = 908 Tons per Month. Units Generated = 390,000 per Month. Coal per Unit = 5·22 lbs.											
B.—*With Increased Motor Load (4 Years):—*											
K.W.		Hrs.	Tons.	K.W.		Hrs.	Tons.	K.W.		Hrs.	Tons.
3×600	6 R 1 B	1	78·5	2×600	4 R 3 B	½	25	1×600	2 R 5 B	1½	41
3×600	6 R 1 B	2	157	2×600	4 R 3 B	1	54·8	1×600	2 R 5 B	6½	177
2×600 1×300	5 R 2 B	1	67·8	2×600	4 R 3 B	½	25				
2×600 1×300	5 R 2 B	1	67·8	2×600 1×300	5 R 2 B	½	28				
2×600	4 R 3 B	2	100	2×600 1×300	5 R 2 B	3	197				
1×600	2 R 5 B	½	14·2	2×600 1×300	5 R 2 B	1	65·5				
				3×600	6 R 1 B	1	76·0				
				3×600 1×300	7 R	1	99				
		Total	485·3			Total	570·3			Total	218
Combined Total = 1,273 Tons per Month. Units Generated = 641,000 per Month. Coal per Unit = 4·45 lbs.											

it being understood that the consumer pays for the cost of service connections.

(4) Stand-by losses can be turned to account by reducing that part of the works cost which is chargeable to coal by some 30 per cent. in the case of supply for motors.

(5) Investigation of "unproductive capital" charges, more especially when combined with a reduction to motor users on the lines indicated, may enable the cost of the lighting supply to be also reduced.

(6) The diagram of stand-by losses will, it is hoped, enable engineers to appreciate better the relative importance of the various losses at different periods of the load, as well as to fix a basis of comparison between stations and hence an individual standard up to which each station should attain, and thereby to effect reductions in "works cost" over and above those considered in connection with the motor load.

TABLE B.

EXISTING "WORKS COST" COMPARED WITH WORKS COST ON "RESTRICTED-HOURS" SYSTEM.

2,000 k.w. on feeders.

	CLASS I.		CLASS II.	
	* Existing.	Proposed.	* Existing.	Proposed.
	d.	d.	d.	d.
Wages	0·15	0·05	0·20	0·05
Repairs	0·20	0·10	0·25	0·12
Oil, etc.	0·05	0·05	0·05	0·03
Coal...	0·30	0·25	0·45	0·30
Works Cost ...	0·70	0·45	0·95	0·50

* Based on present "Works Costs" with combined lighting and motive power, but no traction.

APPENDIX.

Further Explanation of the "Stand-by Loss" Diagram.—Referring to Fig. 12, which relates to mechanical and electrical losses in the engine and dynamo of a 200-k.w. set by Messrs. Allen & Co., the construction is as follows:—

Draw (A B) representing electrical horse-power, (C D) representing brake horse-power, (E F) representing indicated horse-power.

Produce (A B) to (G); join (A D) and produce it to (H); produce (E F) to (K). Set off above (F) an ordinate (F M) equal to (F D), and draw through (M) a line (M L) parallel to (F K).

The Figure (A B F E), which represents the combined mechanical and electrical losses, may be split up into two parts, viz., a part (A E F D) which is constant at all parts of the load, and a part (A B D) which is proportional to the load.

By assuming—which is substantially correct—that the frictional and electrical losses in a 400-k.w. set at full load are *double* that which they would amount to in a 200-k.w. set at full load, we may prolong the diagram indefinitely for any number of engines in parallel up to the limits of the station, adding one shaded parallelogram for every

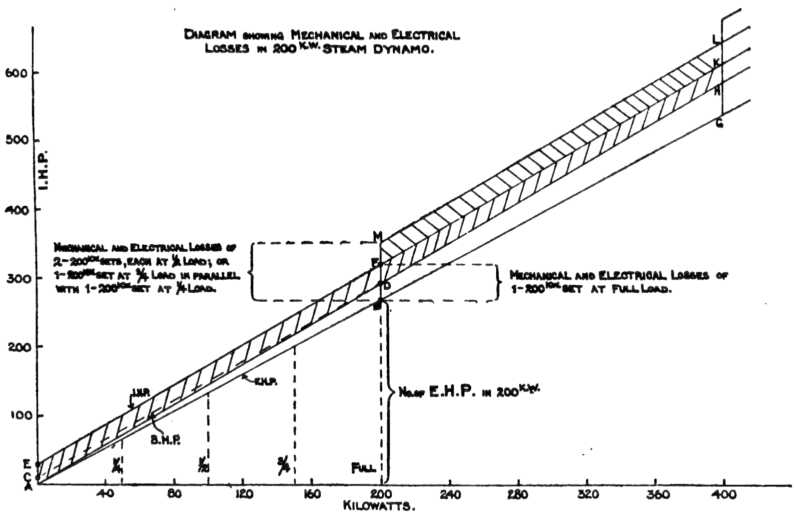


FIG. 11.

additional 200-k.w. set thrown in, or two parallelograms if a 400-k.w. set be thrown in.

The same principle is applied to the boiler diagram shown in Fig. 10 before transferring it to Fig. 7, and in a still simpler form to the steam consumption diagram of the engine.

To know the component sources of the loss is immaterial; all that is necessary is to know the *total* loss, and divide it up into a portion which is a constant and a portion which is proportional to the load.

A diagram is added (Fig. 12) which, though not quite correct as regards actual values, gives a clearer idea than can be obtained from Fig. 7 (owing to the small scale of the latter) of the way in which the stand-by losses are added together. The diagram is virtually the central part of Fig. 7 to a much larger scale, with some modifications in arrangement.

Effect of Size of Station upon Selling Price.—We will now consider briefly how the foregoing estimates of the cost to the consumer are affected by the size of the station. To investigate the items composing

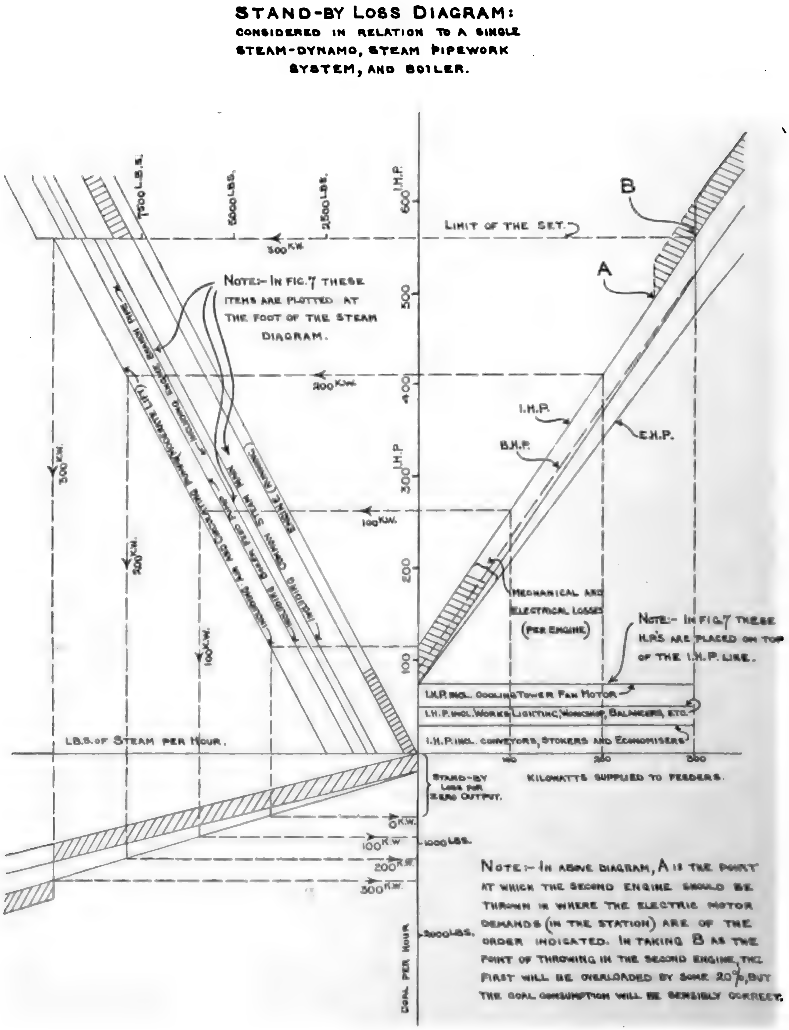


FIG. 12.

"works cost," as affected by size of plant, is beyond the limits of this paper. The author has indicated for a particular case (see Table "B") how these vary with the proportion of motor load, and engineers can, if desirous of applying the results, treat other special cases similarly.

Consider a motor load of Class I., and let us see what is the

minimum price at which we can sell, for a given "works cost." Referring to Table "A," we find the following values taken for a station of 2,000 k.w. maximum demand (Class I.):—

(*a*) Interest and Sinking Fund = 0·45d. per unit, depending entirely upon the capital spent in station and mains, to generate a given number of units annually.

(*b*) Management, Salaries and Office = 0·079d., of which an item of 0·022d. is dependent on the average demand of consumer, and an item of 0·057d. dependent on capital outlay in station and mains.

(*c*) Rates Rent and Taxes = 0·04d. per unit, of which an item of 0·03d. is dependent on the gross earning capacity of the station and an item of 0·01d. on the net profit.

(*d*) Net Profit = 0·18d. per unit.

With reference to (*a*) the author has, as already stated, based this on a capital expenditure of £70 for every kilowatt added to a station of 2,000 k.w. capacity. This might be divided into, say, £40 for land, buildings and plant, and £30 for mains and services.

Now in his recent paper on the "Distribution of Electrical Energy" read before the Institution of Civil Engineers, Mr. J. F. C. Snell has shown that the capital cost of a generating station for 2,000 k.w. diminishes only in the ratio of £31 to £22 per k.w. of plant capacity (including spares) for an increase to 10,000 k.w., and above that is sensibly constant. The item for Mains would, in a larger scheme, probably go up, rather than down, as it would include sub-stations and spare "E.H.T." mains, which alone amount to about £10 per k.w. Hence we may take, say, £20 for generating station and land, and £30 for sub-stations and H.T. and L.T. mains (= £50) as the reduced total capital cost on a scheme of 10,000 k.w.

Hence, for the same load factor,

$$(a) = 0{\cdot}45\text{d.} \times \frac{\pounds 50}{\pounds 70} = 0{\cdot}32\text{d. per unit.}$$

Turning now to (*b*), the first part of this item, viz. 0·022d., will not be materially reduced for a 5 H.P. consumer's motor, even though a power company sell in bulk to a Corporation, for practically the same office staff will be required per unit sold as before. Put it at 0·022d. The second part will, however, be reduced in a ratio considerably greater than the capital costs, say as from 1 to 0·3 per k.w. for a given load factor. Hence,

$$0{\cdot}057\text{d.} \times \frac{0{\cdot}30}{1{\cdot}00} = 0{\cdot}017\text{d. per unit.}$$

The total for (*b*) is thus = 0·022d. + 0·017d. = 0·039d. per unit.

The item (*c*) of Rates and Taxes, etc., next claims attention. The first part (viz. 0·030d.) will be slightly less for a given load factor, because the annual total expenses will be perhaps 20 per cent. less per k.w., and therefore the gross receipts per k.w. can afford to be correspondingly less for a given percentage of profit. Say, 0·025d. per unit.

The second item (0·01d.) being a percentage of the first, will be affected in the same degree, and may be put at 0·008d. per unit.

The total for item (c) is thus = 0·025d. + 0·008d. = 0·033d. per unit. For the same reason,

$$(d) = 0{\cdot}18\text{d.} \times \text{say } \frac{8}{10} = 0{\cdot}14\text{d. per unit.}$$

Hence the total of (a), (b), (c), and (d) is :—

= 0·32d. + 0·039d. + 0·033d. + 0·14d. = say 0·53d. per unit.

From which it follows that if the "works costs" of the station are not less than 0·4d. per unit, it is impossible to sell current, even to large consumers for motive power, under 0·9d. per unit, unless the lighting and motive power loads do not overlap. This applies to motors having a load factor of 30 per cent. taken over the twenty-four hours, but which, however, are only run in the daytime. Where night loads are undertaken, the figures can be corrected by assuming higher station load factors throughout.

In applying the results to motors of Class II., having a smaller load factor, the improved diversity factor must be taken account of in estimating the station load factor.

The figures in column (3) of Table "A" show that the "Restricted-hours" system, even in a station of only 2,000 k.w. capacity, can compete successfully with a station of 10,000 k.w. capacity supplying current under the ordinary terms.

Gas, Oil, and Electric Motors.

A detailed comparison of the cost of these is out of place here; but, as regards the gas engine working with lighting gas, it is fairly safe to say that a gas engine of about 5 B.H.P. (rated) will take at least 25 (to 30) cubic feet of gas per hour per B.H.P. when working steadily with about half its rated load; and 25 cubic feet of gas, at 2s. 1d. per 1,000, costs five-eighths of a penny per B.H.P. per hour. Unfortunately, however—both for gas, oil, and electricity—it is very rarely that an average load can be found corresponding to anything like one-half the full load of the engine, and one-fourth the rated power is a much more frequent proportion (see earlier in this paper). At this output the gas consumption will be of the order of 35 (to 40) cubic feet per B.H.P. per hour, costing, at 2s. 1d. per 1,000 cubic feet, 0·87d. per B.H.P. per hour. To this sum add 0·36d. per hour to cover interest, etc., charges, plus 0·051d. for lubricant, and we have a total of *1·28d. per B.H.P. per hour.*

As regards Oil Motors, taking data from the same source, it would seem that with a 5 H.P. oil motor working at one-fourth the rated load, a sum of 0·3d. per B.H.P.-hour will cover the cost of crude petroleum and lubricant, and to this add interest, etc., charges amounting (with a 35 H.P. motor) to 0·92d. per B.H.P.-hour, giving a total of *1·22d. per B.H.P. per hour.*

Taking an Electric Motor on the same basis, and taking the cost of current at one penny per unit—it will be shown later that 0·5d. can be offered under certain circumstances—and adding 0·225d. per B.H.P.-

hour for interest, etc., on cost of motor, and 0·03d. for lubricant, we have a total cost of *1·25d. per B.H.P. per hour*, exclusive of wages.

The item for wages has been omitted in all the three cases, but it is needless to say that, of the three motors, the electric is that which suffers most from such a method of treatment.

It should also be mentioned that the capital charges in all three cases are based on a 35-H.P. motor,* which, again, unduly handicaps the electric motor.

For instance, if we add 50 per cent. to the capital charge in each case (to express it in terms of a 5-H.P. motor), the respective costs per B.H.P. per hour would be: Gas = 1·47d.; Oil = 1·68d.; and Electric = 1·37d.

The author has been accused of not doing justice to the electric motor, in omitting the item for wages altogether, and he has therefore added an item for this to the gas and petroleum figures given in Table "C."

TABLE C.

Costs per B.H.P. per Hour.				
	Gas at 2s. 1d. per 1,000.	Petroleum at 45s. per ton.	Electricity at 1d. per unit.	Electricity at 0·55d. per unit.
	d.	d.	d.	d.
Gas, Oil, or Current consumed (at ¼-load)	0·87	0·25	1·00	0·55
Lubricant	0·05	0·05	0·03	0·03
Interest, etc., on Capital (+ 50 per cent. to reduce to 5 H.P.)	0·55	1·38	0·34	0·34
Wages (one boy at 5s. per week; part wages only) ...	0·91	0·91	Nil	Nil
Totals	2·38	2·59	1·37	0·92

He has also included in the comparison some figures which he has been given relating to Suction Gas Producers; but there are so many

* See paper by Ade Clark, *Proceedings of the Institution of Mechanical Engineers*, 1903, No. 3, p. 395; *Electrician*, vol. 51, p. 668.

points upon which he requires further information before he could accept the figures as reliable, that he is obliged to postpone this interesting investigation, in the hope that some one better qualified will take it up. Two or three things, however, strike him as worth pointing out in this connection.

First, that with small powers and intermittent loads, wages, if they have to be paid, form an item of quite serious dimensions in the cost per B.H.P. With a suction gas producer plant it seems to the author that this item *must* be allowed for, no matter how opinions may differ as to its necessity for an ordinary gas-engine working off town's gas.

Secondly, the capital cost must be greater than that of an ordinary gas-engine without the producer plant, even if the cost of the engine alone, for a given power, be not greater—which the author believes to be the case.

Thirdly, it will probably be found that, working on ¼ of the full load (the basis of comparison in the table), the cost of the coal for the producer amounts to quite 0·2d. per B.H.P. per hour, and not 0·1d. as has been claimed for the full load.

If this be so, the gas suction producer cannot rival the electric motor at 0·5d. per unit, even though the item for wages be knocked out altogether. To do this is fair for the electric motor, as it can run all day without attention; but the gas producer plant requires stoking up every three or four hours, and lighting up as well as stoking in the morning, not to mention cleaning out at intervals, so that a special attendant would seem necessary.

Discussion at Birmingham, Dec. 14, 1904.

Dr. Sumpner.

Dr. W. E. Sumpner: With reference to the figures quoted as to relative cost of gas, petroleum, and electric power, these are subject to debate, but they do not greatly affect the question, because electric motor development was delayed not so much by the competition of good rival systems, as by the reluctance of owners of old and bad plant to change to a more efficient system. The amount of coal wasted in such old plants, is enormous, the total waste throughout the country from this cause being probably greater than the amount exported.

Mr. Vaudrey.

Mr. J. C. Vaudrey: With respect to the figures quoted as to the relative cost of gas, oil, and electricity for motive power, I consider that it is not in some cases fair to debit the system with the capital cost of the prime mover. It depends upon whether the prime mover is actually in the shop. The proposal to cut off the peak of the load presents difficulties. It is not possible to conceive that the average works will be willing to shut down, as proposed, especially as the amount of energy used forms only a small proportion of the total works cost. Even supposing the peak load to be cut off, I do not believe it possible to bring the charge below 1d. per unit. This is considered to be a bare price even for a traction load. The suggestion

to instal accumulators on consumers' premises, especially on the small scale proposed, is impracticable. Had it been feasible, it would have been done long ago. Mr. Vaudrey

Mr. J. A. JECKELL: I question Mr. Taylor's assumption that 1 B.H.P. requires 1 unit of electrical energy. At Coventry, where the average price obtained for motive power was 1·3d., the revenue obtained is only ½d. per B.H.P. hour. As regards interest on capital, the figure of 0·31d. per B.H.P. annum for a 17 H.P. motor working 2,500 hours, gave £54 17s. 11d. per year. Such a motor could be bought for £57. I do not see why the restricted-hours system should not be offered to consumers, but the special circumstances existing in each town would have to be considered. All things considered, the figures given by Mr. Taylor did not show electric driving in anything like so favourable a light as they should do. Mr. Jeckell.

Mr. R. A. CHATTOCK: I should have liked a fuller explanation as to what is meant by continuous and intermittent loads for motors. At Bradford a scale was introduced of 1d. for continuous and 2d. for intermittently loaded motors. By continuous it is meant that the motor must be running all day, whether actually loaded or not. I have known people to run all day on no-load in order to obtain the low rate. The average rate was 1¾d. Under these conditions we found that the motor load just paid for itself. I feel sure that a charge of 1d. per unit, without restrictions, would not pay. It might at first, but after the load had developed, the average price received per unit would fall to too low a value. Switching off consumers at certain hours may do in trades where firms can pick their men. Another point not yet referred to is that gas companies do not restrict the hours during which gas engines may be run. I do not agree with the scheme of putting in cells to tide over the peak load. I believe this has been tried by a London Company, but has been discontinued, as after two years it was found that most of the cells were ruined. The hiring out of motors to consumers is a good plan, and very good motor loads have been secured in this way. There are 600 to 700 motors on hire at Bradford. Mr. Chattock.

Mr. R. P. WILSON: The author has shown that electricity can be profitably supplied to continuously loaded motors at a price which will compete favourably wtth other prime movers, provided that this supply is not saddled with interest charges; it therefore follows that within practical limits it can compete for intermittent loads. The actual load factor of such prime movers need not be considered. A load that does not overlap lighting or necessitate capital expenditure, is nothing more than a by-product. If Gas Company's by-products were saddled with the cost of production on the same lines, there would be no market for them. If it is correct to say that the revenue from any class of consumer should be proportional to the plant they monopolise, then the time-switch produces the desired result, as is shown by the following figures relating to Dudley: Current consumed by shops, 25 per cent. of total; plant monopolised, 43·5 per cent.; revenue provided, 42·7 per cent. Mr. Wilson

Mr. Shawfield.

Mr. C. E. C. SHAWFIELD: I do not agree with the author's pessimistic view that current cannot be sold at a lower rate than 1d. At Wolverhampton the total cost of supply by Wright's method can be allocated as follows: Preparation costs £7 10s. per annum per k.w. demanded + a production cost of ¼d. per unit, a figure which would certainly improve on an increased load factor. These figures can be equalled or improved upon by many stations, and they justify the offering of low prices to users of motive power. At Wolverhampton the average tramway load factor is 25 per cent.—even lower in winter; while that of the private motor consumer is slightly better, and tends to improve as more motors are installed. The diversity factor of private motor consumers is approximately 2, which, according to Mr. Taylor's statement that the load factor is practically the reciprocal of the diversity factor, should correspond to a load factor of 50 per cent. This, however, is an almost impossible figure, not reached by any tramway in the country, with the exception perhaps of Liverpool or Glasgow. I would not trust to the consumer switching off his motor during the peak of the load. Unless automatic means are provided, there would not be many motors cut off. I also advocate the abolition of the clause which prohibits the granting of preferential tariffs to any consumers. Other commercial undertakings are not hampered by such a restriction. Every supply station should be free to make the best bargain it can with any consumer, subject only perhaps to a restriction as to the maximum price to be charged.

Mr. Pringle.

Mr. P. J. PRINGLE: In connection with fuel costs, I think that allowance should be made for the fact that the boilers are not forced during the day to the extent they are at times of heavy load. They can therefore burn a cheaper grade fuel during the day. The total charge to consumer of ⅜d. per unit estimated by Mr. Taylor seems a very safe value, which I consider might well be reduced. The additional capital outlay at generating station of £70 per k.w. at motor was high. Many stations 6 to 10 years old could to-day provide plant at station and allocate a fair proportion for mains at a much less figure than £70 per k.w.

Mr. Morcom.

Mr. R. K. MORCOM: There is a strong case against shutting down at certain fixed hours. I have some figures relating to a factory in which the machinery is driven by electric motors. For every £1 of manufactured goods sold, about 1 unit of electrical energy is consumed. As one of the chief things that has to be looked to is to get stuff out of hand quickly, there would have to be a proportionally heavy drop in cost per unit, in order to make it worth the while of a manufacturer to shut down his works. My experience is that the number of units used in machine shops is being continually pushed up on account of the higher speeds of working now adopted.

Mr. Fennell.

Mr. W. FENNELL: The proposal to supply electricity to day users only at a low rate, has been carried out for the past nine months (since commencement of supply) at Wednesbury, and two-thirds of their motor load is already supplied on that system. To the long hour user

they offer as an alternative the maximum demand system. They have no difficulty in connection with time of cutting off. The electrically driven clock switch of the Reason Co. is very satisfactory. It can also be made to act as a throw-over switch in connection with a two-rate meter, where the motor is required occasionally in the evening, a rate of 4d. or more being then charged. Mr. Fennell.

Mr. ARTHUR WRIGHT (*communicated*): The success of The Reason Manufacturing Co.'s time switch at Brighton and other towns is undoubted. At Brighton there are now 225 of these instruments in actual use. I do not agree with the author in reference to the diversity factor, as I consider that it would vary from a figure over 10 in the case of lift motors down to 1 in the case of pump motors. This question of diversity factor cannot be treated except by the method of probabilities. I consider 5 as a better average figure than 1½. In reference to the author's remarks respecting fog loads, it is an interesting fact that in Stepney, during the darkest fogs they have had this winter, the fog peak has never equalled the evening peak. Mr. Wright.

Mr. J. CHRISTIE (*communicated*): The system used at Brighton is most successful in every way. Fortunately there is a large and steady demand for lighting in the evening, and the standing charges being met by the higher rate charged for this lighting, we can, at a profit to ourselves, supply as much current at 1d. per unit as our day-load consumers liked to use, as they have simply to pay for coal, repairs, and attendance, which are easily covered by the sum charged. I do not know what proportion of 1d. units are sold, but I estimate that they amount to close upon ¾ million units, which would otherwise never have been obtained. Mr. Christie.

Mr. GEO. WILKINSON (*communicated*): I do not agree with the figures regarding gas consumption upon which Mr. Taylor has based his comparisons. Was he aware of the wonderful advances made in the economy of working gas engines? I refer to the suction gas plant by means of which gas is produced in a very simple form of producer by the suction of the engine piston itself. Only recently I paid a visit to works where one of these plants was in operation. The engine was a 25 H.P., and the gas producer supplying its gas fuel was a very simple apparatus indeed, with no moving parts, the selling price of which was £90. This producer and engine were giving one B.H.P. per hour for fuel costing one tenth of a penny when using anthracite coal in the producer, and the engine had been running three months without any attention whatever. In my opinion the Power Companies have more to fear from the ordinary gas engine and suction producer plant than from any other competitor. Mr. Wilkinson.

Mr. A. M. TAYLOR (*in reply*): With reference to the objections raised by Mr. Vaudrey and others to cutting off the supply at certain fixed times, I think the best answer is to call their attention to the places where this system has been successfully adopted. At Brighton they are selling 750,000 units solely by this method, using the time switches Mr. Taylor.

Mr. Taylor. of the Reason Manufacturing Company. In several other towns the system was being given a trial, notably at Wednesbury. The contention that, because a charge of 1d. per unit would barely be remunerative in the case of traction, it will also, therefore, be unremunerative in the case of a motor load, which is cut off before the lighting peak comes on, is sufficiently answered by Fig. 1 of the paper, which shows the effect of the traction load in requiring additional generating plant, whereas the motor load with the restricted peak requires none, even under the most extravagant assumptions as to its general adoption in preference to an interest-paying rate, and with all necessary margin allowed for the clashing of the day-fog load with the motor load.

In reply to Mr. Jeckell, I have assumed, for purpose of comparison, that 1 B.H.P. requires 1 unit. My figures are based upon the consideration of a 5 H.P. motor, whereas Mr. Jeckell spoke of larger-sized motors, which, of course, reduce the energy consumption per H.P. hour, as well as the capital charges, for the electric motor. Mr. Jeckell sold a unit for 1·3d. and obtained ½d. per B.H.P. hour; hence the energy sold per B.H.P. hour averaged 0·385 unit. But to do a B.H.P. hour with less than 0·746 unit requires an efficiency of over 100 per cent.; hence it would seem either that the meter were inaccurate or, what is more likely, that Mr. Jeckell's estimate of the H.P. hours was based on incorrect information supplied to him by consumers. As regards interest, etc., on capital, Mr. Jeckell obtains his figure of £54 17s. 11d. by taking the full load of 17 B.H.P. for the 2,500 hours; but he has overlooked the fact that my figures are for a motor working at a quarter of its rated full load, hence the value should be multiplied by 4. The figure given in the paper also includes 10 per cent. per annum for maintenance; but it is, no doubt, quite 30 per cent. too high, as discount was, by a slip, not deducted in the case of the electric motor.

In reply to Mr. Chattock, the "Continuous" motor, considered in "Case 1," runs at full load all the day, and is, of course, an extreme case. The "Intermittent" motor, considered in "Case 2," runs for two hours, one hour, or any other period of time, with a varying load averaging *one half* the rated H.P. of the motor; it is then shut down for a similar period, and the cycle of operations repeated. I am glad to note that Mr. Chattock practically corroborates the conclusions arrived at in the paper.

In reply to Mr. Shawfield, I did not follow his figures for "preparation" cost and "production" cost. The former, when multiplied by the maximum observed load on the feeders, gives us (according to *Lightning*):—£7 10s. × 1,295 k.w. = £9,710 per annum; and when to this we add the "production" cost, viz.: (1,971,794 units × 25d.) = £2,050 per annum, we obtain a total of £11,760 per annum. But this should be equal to the gross revenue, which is £21,370; and it would seem that Mr. Shawfield has multiplied his station kilowatts by his diversity factor, which I submit is wrong, unless the £7 10s. is the charge per k.w. of each individual consumer's

maximum demand. It is very interesting that Mr. Shawfield's "production" cost comes out at less than one-third of his works cost and at only two-thirds of his actual coal bill. If correct, these figures bear out my own deductions in the most interesting way, and in fact show that his assumptions are too conservative rather than the reverse. Mr. Shawfield has misunderstood me about the "diversity factor." It is only the extreme possible *limit* of the diversity factor (for a particular class of motor) which is the reciprocal of the load factor, the latter being taken only over the working day, not over the night as well. The actual diversity factor will be anything between unity and this limit. If the limit, for example, is 4, as in Case II. of the paper, it is extremely unlikely that the actual figure will reach 2, and hence 1·5 is a safe value to estimate upon. Mr. Taylor.

Mr. Arthur Wright's remarks as to diversity factor have been practically answered in my reply to Mr. Shawfield. I hardly fancy that the figure given (10) is an actually observed diversity factor among a number of motors; but I accept with deference anything coming from Mr. Wright on this question.

In reply to Mr. Pringle, I agree that a less sum than £70 per k.w. might have been safely taken. On page 256, however, I deal with existing charges, and I do not think less than £70 per k.w. can be taken in that case.

In reply to Mr. Wilson, all I claim to have proved in the paper—so far as the comparison between electric and other motors is concerned—is that, for intermittent loads and for units not larger than 5 H.P., electricity makes the best showing. Perhaps the limit might be extended to 15 H.P., owing to his having fixed the interest, etc., charges rather too high, as explained in his reply to Mr. Jeckell. It must be remembered that the interest, etc., charges would be quartered on the continuously-loaded motor of Case I., both for gas, oil, and electricity; and this counts in favour of the two former.

With reference to Mr. Geo. Wilkinson's communication, I would like to know how the B.H.P. hours were measured, the proportion of load at which the engine ran, and whether it ran continuously day and night; also the exact amount of attention needed by the producer.

Discussion in London, May 4, 1905.

Mr. C. P. Sparks: I have some difficulty in making any remarks on this paper owing to the somewhat novel treatment of the subject, and the fact that the consideration of it would take a great deal more time than I have been able to devote to it. From glancing at the paper I am disposed to disagree with the author's treatment of the subject on one or two points. On the opening page he advises us to secure the motor load at once, because the developments in other motors are going on so rapidly that there will be no field for the electric motor. There, I think, the author is entirely wrong, because, whatever form of prime mover is required, the actual motor of the future is undoubtedly the electric motor. The question really is, Is Mr. Sparks.

Mr. Sparks. the supply of electricity to be taken from the public supply mains, or is it to be generated upon the premises themselves? There is no question that the actual drive must be electric—I am not speaking of small motors, perhaps of 1 or 2 H.P., but where you are dealing with motors in factories running up to 30 or 40 H.P., the drive must be electric. The next point is in connection with continuous *versus* intermittent motor loads. A large part of the paper is based upon the question of diversity factor. The diversity factor is assumed in a certain case to be unity, and in another case 1½. No doubt the usual training of the electrical engineer with regard to the diversity factor has been a bad one, because first of all we were dealing entirely with lighting business. The diversity factor in lighting is poor, as light is principally required during hours of darkness; consequently we have been trained to expect a somewhat poor diversity factor; but in the motor business it is somewhat difficult to tell at first what the diversity factor is, because the lighting in the first instance being the principal business, and then having the motor load superimposed upon the same circuit, it is not easy to distinguish between the two. But in my opinion the diversity factor assumed by the author is altogether erroneous, and should have been very much higher. Consequently the capital charges would become of less importance than those given in the paper. With regard to the cost of generation, again, the electrical engineer's training has been, as a rule, with poor load factors, and I think the cost of generation of these power units has been assumed at much too high a figure. The last point I wish to touch on is the question of intermittent supply during certain hours. There may be some people here and there who might consent to have their supply cut off, but in many towns the hours of darkness, or possible darkness, are so great that an intermittent supply would be almost valueless. In my opinion such a supply is entirely impracticable. We have either to give a continuous supply of energy available at all times, or else retire from the business and allow somebody else to come in and do it.

Mr. Tapper. Mr. W. C. P. Tapper: When I read this paper the first paragraph led me to hope for some practical hints as to how to develop the motor load, but I am afraid when I read the conclusions my hopes were somewhat damped. The only thing I find there is the suggestion that we should use a restricted hour system. I am afraid if there is nothing better to offer than that we may as well give up all hopes of ever dealing with large manufacturing loads. In Stepney we actually tried that system for some time, and we found that it was necessary to drop it, or we should have lost the few large customers we had at that time; in fact, in two cases we had the consumers running large gas engines after dark, with motors in the daytime, and they came to the conclusion that they must adopt either one or the other exclusively, so we consequently gave up our effort to run that system. With regard to the question of diversity factor, I agree with Mr. Sparks on that point in thinking that the author is altogether wrong. In Stepney we have a diversity factor, as near as I can calculate it, of something like 4·4, which is increasing year by year, and is already more than the author admits is possible in

his paper. There is no reason why that figure should not go up in certain cases very much higher. I believe in tramway stations it would be considerably above that. In the case of the Glasgow tramways, for instance, the average kilowatts on the station per car is about 7·75, whereas with a large car starting fully loaded uphill the kilowatts must be very much more than that, probably between 50 and 60 k.w. at the moment the car starts, so that in that case the diversity factor would be something like 7. I have gone into the Stepney figures as compared with those mentioned in the paper, and I find that the stand-by cost per kilowatt—that is, per consumer's kilowatt, not station kilowatt—works out at about £7 per annum. If this is divided by the motor diversity factor, which is perfectly justifiable in my opinion, the stand-by charges, including interest, sinking fund, and other stand-by items, are £1 15s. per annum; and with a running cost of 0·54d. per unit it works out at 1·7d. per unit for one hour's daily supply, and 0·54d. afterwards. We therefore consider that our flat rate of 1d. is perfectly justifiable. It may be argued that if it costs 1·7d. to supply during the first hour, 1d. charged during the first hour would result in a loss. But there I think the question of diversity factor comes in. In the case of motors with a large load factor the diversity factor would be small, but for a motor running for less than the equivalent of one hour a day at its maximum load, obviously the diversity factor must be high; the shorter the time it is running per day at its maximum load the higher the diversity factor. For this reason I think it is possible to supply motors profitably at a rate which may be below the average works costs per unit. Mr. Tapper.

Mr. J. S. HIGHFIELD: I do not know that I have very much to say on this subject, but it certainly appears to me that the tone of the paper is rather a despairing one from the supply companies' and the supply authorities' point of view, and, like Mr. Sparks and Mr. Tapper, I do not agree with the author. I think the supply companies can certainly supply motors at a price at which it will pay manufacturers on a large scale to take the current; in fact, they are doing so in many towns on a large scale. There is one point that has not yet been referred to in the discussion, *i.e.*, the question of the overlapping of the lighting loads and the whole of the motor load peak due to the fogs. In the paper I think the author finds that the ratio of the maximum day peak at times of fog to the maximum night peak in December is something like 60 per cent. On the Metropolitan system we find it is very nearly 80 per cent., so that that difficulty is rather exaggerated in London as compared with provincial towns. There is no doubt that it makes the allowance which has to be made for capital charges for the motor load very considerably greater than they otherwise would be. The motor load improves the load factor from week to week. There are two figures for load factor that must be taken in considering the price per unit. One figure—and that is the common one—is taken over the whole twelve months, and is calculated by taking the maximum load, say, some time in December, and the whole of the units sold during the year. It is quite possible to conceive a system, especially a new system just starting out, where, owing to very good canvassing, the load rises Mr. Highfield.

Mr. Highfield.

at an immense rate, so that the connected load in December is at least twice as great as it was at the beginning of January. Consequently the maximum load is very much greater than it should be in proportion to the units sold; that is to say, lamps have been connected which show a big maximum in December, and for which no units are shown during the rest of the year, so that the load factor looks exceedingly small. It would be argued in the ordinary way that therefore the works cost would be very high, whereas it is found often not to be so. This load factor is a function of the capital charges per unit, but not of the works costs. If, however, the load factor is arrived at by taking the maximum load in any week, and the units sold during that week, it will be found that the load factor is very much higher than it would be for the whole year: this is particularly true when there is a good motor load, and it is this load factor that is a function of works costs. A system supplying a large motor load, that is to say, large as compared with the lighting system, often shows a higher load factor in the summer months than in the winter months, so that the motors enable energy to be produced during the summer at a price which is much lower than it would be without the motors: by increasing the load factor during the summer they also make up for the less output of energy. The works costs which must be set down for the motor part of the supply are very much less than would appear by taking the average works costs for the whole year as though the motor load was not there.

There is one difficulty we always have to face on lighting circuits, to which also there is no reference in the paper, and on which, perhaps, the author would say something in reply, and that is the question of charging for quite small motors. Very often in private houses and small shops, and even at works, there is a large quantity of lighting and requirements for quite small motors of 2, 3, 4, or 5 H.P. If a separate rate is charged for motors and a separate rate for lighting, two circuits have to be run, and very often that is exceedingly awkward. What is wanted is some sort of system of charging that will enable the price to be reduced for the whole supply, both for lighting and for motors, so as to include the motors. I am not going to put forward a suggestion. I have thought of this for a good many years, but I am bound to say I have not found out any way of doing it; but I raise the point now in the hope that some ingenious gentleman will get up and tell me how to do it. There is another point about the load factor and about the overlap in the peaks in connection with tramways, if there is a tramway supply in addition to the lighting supply—and with a power company supplying a railway I suppose the same advantage obtains—and that is with regard to the fog difficulty. It is very much less when a tramway supply and a lighting supply are given from one station, because when the fog comes on all the lights go on, but the tramways are compelled to shut down, therefore the total peak does not get at all out of hand, and there is no need to worry about the tramway peak coinciding with the fog lighting peak: it is a beneficent arrangement of Providence. Then it is a curious thing, but if you happen to have a district which is long from east to west as compared with from

north to south, you can always supply current at a less price than you can if the district is long from north to south and short from east to west. There are two reasons. One, of course, is the sun reason; and the other reason is that the traffic always moves from east to west and west to east. People leave their work in the evening going from the east to the west, and as they walk they turn on their light, so that you have a much better diversity factor in that way. Mr. Highfield

Mr. J. A. JECKELL: The point I propose to deal with is Table C. Probably some of you know that for the last two or three years I have been trying to push electric motors *versus* gas engines in Coventry, and therefore it is not a weekly occurrence, but a daily occurrence, with me to compare the costs of running gas engines with electric motors; and I am bound to say that the figures given in Table C. are not in accordance with practice. If Mr. Taylor came down to Coventry and tried to sell gas engines with the guarantee which appears in Table C., I would be delighted, because I should beat him; if he came down and tried to sell electric motors with the guarantee that appears in Table C., he certainly would not sell them against the gas-engine maker. I think most of you, gentlemen, know that one of the troubles of the electrical engineer in the past has been in trying to push electric motors, and anything that militates against that is to the detriment of the electrical profession generally. I hold that the figures which appear on page 259 do certainly militate against the electrical profession. I do not know for one single moment how Mr. Taylor can possibly have arrived at those figures. The first line shows that an electric motor, with electricity at 1d. a unit, costs 1d. per B.H.P. to run for an hour. That is the figure which the people who support the gas engine in Coventry have been pushing down my throat and the throats of consumers for the past three years, and that is the figure which I have had to fight; and it certainly seems rather hard that a member of one's own profession should bring that figure up again, because it is so absolutely wrong as regards practical experience. I will lay before you, if you do not mind, some *facts*. The price per unit assumed in the paper is 1d. One ¼ penny is the average price which we have received during the last year for the current we have sold for motors. Therefore, according to Mr. Taylor, the cost per B.H.P. is 1·25 per unit per hour. I put this question to Mr. Taylor at Birmingham: "Do you mean to say that a 50 H.P. motor with electricity supplied to it at 1d. a unit will cost 4s. 2d. an hour to run for every hour it is run throughout the year?" and he said "Yes." Well, I say "No." If it was, I should not have sold a single motor. We will take the actual facts as they appear from the station; afterwards I shall be very pleased to give you the facts as they appear to the consumer. We have sold during the year ending March 31, 1905, 854,503 units. The revenue we received from these is £4,385. The average price, therefore, works out at practically 1·25 per unit; actually, I believe it is 1·22d. The motors on the circuit on April 1, 1904, were 101; they totalled 674 H.P., which works out at 6¾ H.P. per motor. The motors on the circuit on April 1, 1905, were 1,136, which works out at 7 H.P. per motor. The reason is that the motors we have Mr. Jeckell.

Mr. Jeckell. been putting on during the last year have been chiefly in the larger factories. The average H.P. of motors during the year is 905. I think that is a fair figure to take, because we have been connecting the motors throughout the year. The average number of units used works out at 944 units per H.P. per annum. That figure has been checked quarter by quarter and appears correct. The average cost per H.P. per annum for current is, therefore, £4 16s. 10d., that is at any rate the money we have received for it. I am assuming 2,500 working hours in the year, although I am bound to say that the larger proportion of our motors are installed in factories which have been running overtime and full time—some of the motors have been started on Monday morning and not stopped till Saturday night. Therefore this works out at 0·46 per B.H.P. per hour, as compared with Mr. Taylor's 1·25d. If Mr. Taylor's figure is correct, I could not get rid of any motors. I hold it is not—in fact, I am perfectly sure it is not. These figures are in reply to Mr. Taylor's figures as regards the supplies of electrical energy. Now I have some figures here which were very kindly given to me by a factory which tried electric motors *versus* gas engines. Perhaps you are not aware that Coventry stands, I believe, second in the United Kingdom as having the largest number of gas engines in proportion to the population; I believe Kettering stands first. The people in this factory took out a gas engine of 36 I.H.P., and put in certain motors. I will give you the exact figures as they have been given to me, and then I will put them into a schedule, as Mr. Taylor has done. I will remind you, gentlemen, that it depended upon the result of this balance sheet whether we drove the whole of their works electrically or not. These are not my figures, they are theirs, and they decided from these figures to go in for electric driving throughout the whole of the factory, and they are absolutely satisfied with the result. But these are not figures which coincide with Mr. Taylor's. With gas engines using gas costing 2s. 4d. per thousand cubic feet, the gas cost £58 14s. 4d.; a proportion of the engineer's wages came to £6 16s. 2d.; depreciation, interest, repairs, and oil also came to so much, the total for the gas engines amounting to £76 7s. 10d. They put in the motors. I might perhaps say, with regard to the price of the current, that we charge for the first 2,500 units per quarter, 1¾d. per unit, and all the rest at 1d. The object, as you will readily understand, is to cause the man with the small motor, whose costs of connection, entries in books, etc., are equal to a man with a huge bill, to pay a little more, so that we give the bigger consumer the preference. The cost of the electric motors came to £65 6s. 1d., as against £76 7s. 10d., for a gas engine, so that the difference in favour of 36 H.P. electrical motors for one quarter came to £11 1s. 9d. On the other side of the balance sheet they say, "No account taken of water used, and no account of floor space now set at liberty by use of motors." I can go further, and say the manager told me that it was no unusual thing when they used gas engines for four or five girls to be taken out in an afternoon fainting (a large number of girls is employed in cycle factories), whereas, during the last eighteen months with electric motors, not one girl had fainted.

That is his statement, not mine. Let us compare this figure with Mr. Taylor's. On page 259 he assumes that the gas at 1s. 1d. a unit will cost per B.H.P., 0·87d. I have taken this firm's figures, and just run them out in the same way. According to these people, the cost of gas is 0·47, as against 0·87. These are practical figures. The lubricant does not appear as 0·05, but as 0·01; the interest and redemption not as 0·55, but as 0·048; the wages do not appear as 0·91, but as 0·088, making a total per B.H.P. per hour of 0·616d. for electricity, as against 2·36 given by Mr. Taylor; that is to say, with gas driving an engine 2,500 hours a year, according to Mr. Taylor, would cost £24 15s. 10d. per annum per B.H.P., but according to these figures it works out at £6 18s. 4d. I have been through the accounts of many factories in Coventry, and the average that you can reckon upon is, that a gas engine will cost, including gas, lubrication, wages, and repairs, between £6 5s. 0d. and £7 per H.P. per annum. These are figures which we have checked over and over again. With regard to electricity, the electricity that these people received was at 1·04d. per unit, as against Mr. Taylor's 1d. There is no difference, of course, here. But according to Mr. Taylor's figures, these electric motors ought to have cost £14 5s. 5d. per B.H.P. per annum. Actually, they cost £5 17s. 11d. You see there is a great deal of difference between figures in the paper and actual practice, and I am bound to say that I have to enter a very strong protest against these figures. I have already lost a 50 H.P. job through Mr. Taylor's figures. The gas-engine man is up against me in Coventry. He ignores Mr. Taylor's figures in regard to the gas engine—I wish to goodness he would accept them, but he does not—but he accepts Mr. Taylor's figures with regard to electric motors. He says to my would-be consumer, "Oh, but Mr. Taylor says this is going to cost you so much; it is no good Mr. Jeckell saying it is only going to cost you so much." Mr. Jeckell.

Mr. W. H. PATCHELL: I think in discussing this paper we are somewhat handicapped. I read this paper through twice, and then I did not understand it. I find some of the diagrams obscure, especially Fig. 7. If the author would make it clearer the paper would be of more use to us. It must be studied several times before you can find out which are ordinates and which are abscissæ, and even then you are not quite certain whether you are right. With regard to the question of diversity factor, a friend wrote asking if I would put in some figures of our experience, because we are now supplying from the Haymarket to Aldgate. It might be thought that, with such a district, the shape of the curve would be considerably altered; but it is not; the shape of the curve is materially the same. Fig. A. shows the Charing Cross Company's output for the West End, which goes from the Haymarket to Temple Bar, and for the City, which goes from Temple Bar to Aldgate, and also, plotted on the same scale, the combined curves. It will be seen the peak of the two practically coincides. Nearly thirty theatres in the West End areas hold up the curve a good deal later in the evening, but otherwise the two curves are very much alike. With regard to the question of motors, in one theatre there is a large number of motors; and I have not been more dis- Mr. Patchell.

Mr. Patchell. appointed during the twelve years I have been at Charing Cross than I have over that theatre. It is where the Derby is run, and it may interest the meeting to know that the Derby takes 150 kilowatts for one and a half minutes twice a day. If the load-factor at Epsom is anything like that, I wonder they can afford to keep it up! With regard to the use of accumulators spaced about the district in small quantities, I think Mr. Taylor cannot have had very much experience in that direction, otherwise he would not be so sanguine. If we could get accumulators out on the mains instead of in the stations it would save copper in the feeders naturally. Mr. Taylor rated the maintenance figures at 12, 24, and 36 per cent.; I would suggest he put 100 in front of those figures, and then he would be nearer the mark. It must be

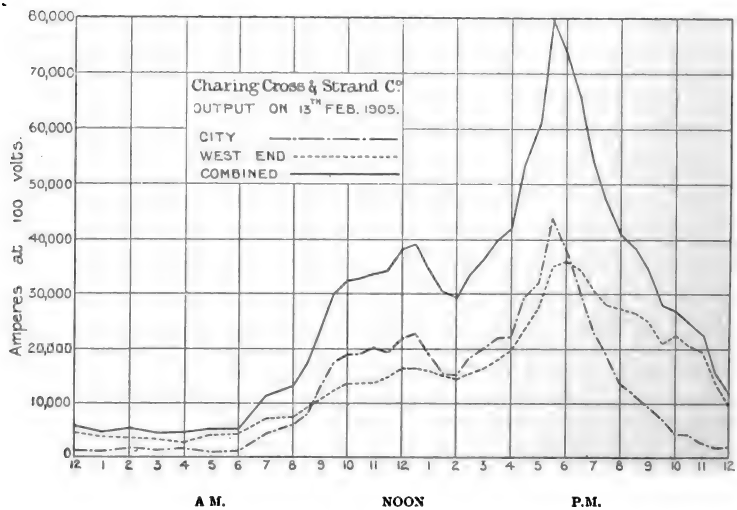


FIG. A.

borne in mind that such accumulators would never be looked after. I have stood at the sick bed of many accumulators; so I am not speaking entirely off the book when I say that accumulators in small quantities which are looked after to a negligible quantity take the maximum amount of maintenance, and if such plates will stand a year, it is more than I have found they will do. Mr. Highfield mentioned the load obtained by motors and lamps respectively. I think it is sometimes forgotten that, while it may not pay to take a motor at a rate *per se*, many lamps are frequently used in connection with it, so that light is being sold all the same time that the motor is running, which is, of course, a compensating advantage. There is another advantage which we electrical engineers do not get credit for, namely, that many basements electrically lit can be used which would be quite unusable if they had not those advantages. In spite of that, we do not get any credit for the rent which can be

Mr. Patchell.

obtained from those basements; we are expected to supply motor-power at bed-rock prices. On the question of diversity factor, the West Ham engineer was telling me an interesting point lately with regard to their load. I was suggesting to him that the lighting load and the motor load would overlap in accordance with the general experience. He said it was not so, but that in this district the motor load was almost entirely in factories, and the lighting load was principally in shops, and a good many of them of the class which does not open until the factories are closed, so that they get a flatter peak.

Mr. Vignoles.

Mr. W. A. VIGNOLES: I was very much interested in reading this paper, as I have, during the last two or three years, been studying the question of stand-by losses, and have introduced in Grimsby a system of restricted hour supply. The author says that electrical energy cannot be sold below 1d. a unit. In my opinion it is not necessary to sell current below 1d. a unit except in very special cases, say, for motors running twenty-four hours per day, six days a week; 1d. a unit is a very fair market price for energy even in large quantities. For example, I installed a 50 H.P. motor in the place of a 38 H.P. gas engine. The gas engine was up-to-date and had been overhauled several times and the valves altered in order to reduce the consumption of gas to a minimum. It would have been very much better to have installed several motors, and then I think there would have been a very big saving in the cost of running. Mr. Jeckell mentioned a case of a 38 H.P. gas engine which was replaced by several motors where the saving was very large. But in the case I have mentioned with the current at 1d. a unit, the first year's bill for electricity was exactly the same as the previous year's bill for gas. The people were quite satisfied, as they were able to use their engine-room, which was downstairs, for other purposes, the motor having been fixed upstairs.

Referring to Table A., under motors Class I., Mr. Taylor considers a continuous load of 9 hours per day. I do not think that is a very good case to consider, as, if a motor runs at absolutely full load, it generally runs 24 hours a day and probably 6 days a week. If it is run only 9 hours a day the load is nearly sure to be variable, and the diversity factor then comes in and helps things. Referring to the details of the table, under Class I., Mr. Taylor takes the works cost at 0·7d., and he takes the works costs for the restricted hour system at 0·45d. If it is fair to take 0·45 works cost for the restricted hour system, it is fair to take it, I think, for Class I. If that allowance is made it would reduce the selling price in Class I. to 1·25d., which is a market price for use with motors of 5 H.P., the size the author is considering. I think the prices suggested for the restricted hours are altogether too low, as the net profit given as 0·06d. per unit works out at only £1,400 on 5 million units. I am sure that is not nearly enough. Five million units would probably be divided among 5,000 or 6,000 different customers, necessitating the rendering and collecting of about 20,000 (quarterly) accounts. The total profit per kilowatt of demand works out at 16/6d. per annum, which on a small motor would certainly not pay the interest and

Mr. Vignoles.

sinking fund on the service connection. You will notice that no interest or sinking fund is allowed in Table A. on the restricted hour system, but interest and sinking fund are always required on the cost of the service connection, meter, etc.

In Grimsby, energy for power purposes is charged on a sliding scale, beginning at 2¼d. per unit, and going down to 1¼d. Then, as an alternative, there is a time switch system with a flat rate of 1d. per unit. A charge of from £2 to £4 is made as a rental of the time switch. This rent covers the cost of management in connection with the consumer, entering and rendering the account, etc. I have found this system to be an excellent advertisement, and in thirteen months we have put on something like 250 H.P. in motors, of which 160 H.P. is supplied on the time switch system. In several cases I know the consumers were attracted by the 1d. per unit, but on going into the matter they found that the time switch system did not quite suit them, and decided to take power at the ordinary prices. Of course, in an engineering works a time switch does not suit, owing to repair work being wanted without delay. The times at which current is cut off at Grimsby is about an hour later all through than the times suggested in the paper.

I hardly think the author is serious when he makes the suggestion of installing batteries on a consumer's premises. If batteries are desirable to deal with the peak load the proper course would be to build battery substations, and so avoid loading the feeders. Then Mr. Taylor thinks it will cost 0·45d. per unit, to maintain the battery; for 0·45d. per unit, he could, in my opinion, allow power consumers the use of the plant, and the batteries would not be required at all.

Referring to the Wright's diagram, Fig. 5, at Grimsby, the average works cost during the past year was 0·75d. while every extra unit sold for lighting or power would cost about 0·35d. (works cost). That is worked out from a similar diagram to Fig. 5. In order to check Fig. 5, Mr. Taylor constructed his stand-by loss diagram. I have dealt with the matter in a different way. I tested the steam consumption of the plant as a whole against the actual load on the works, and the result was a straight line showing somewhat the same results as the author, but with the steps smoothed out. (See the left-hand top side of the diagram.) From the tests made I found that the cost of fuel for every extra unit sold amounted to 0·15d. per unit, as compared with the cost from Wright's diagram of 0·35d., and therefore there is a difference of 0·2d. for extra oil, wages, etc., required in producing the extra current. I made a number of tests, the results of which were published in the *Electrician* of April 28, 1905, so that I will not refer to them any further, except to say that they generally agree with the author's calculated results. I do not think the diagram will be of very great assistance, the labour in compiling it is too great, and I think it would be much better actually to test the steam consumption in the works, and then, if it is thought to be too high, alterations can be made, and further tests will show if any improvement has been made.

Mr. Vignoles.

I think we should acknowledge the amount of labour Mr. Taylor has put into this paper. It is certainly prodigious, but, unfortunately, the paper does not make light reading. I certainly read it through several times, and found the diagrams very difficult to understand. But still I think we ought to thank him for the work he has done, as a paper like this very often makes one see things in a new light.

Mr. Dawbarn.

Mr. R. A. DAWBARN: There is one point on which I should like to make a few remarks. I do not understand why Mr. Taylor suggests that a motor load should be considered in any way as a by-product. It appears to me to be due to the accident of electric lighting preceding the demand for power and motors to a very large extent that we have rather got into the habit of saddling everything on to the poor lighting load. As far as I gather from this paper, Mr. Taylor suggests that all the capital charges for the entire system should be put upon the lighting. It seems to me that, while it is unnecessary to distribute the capital charges at a uniform rate per unit sold, which would, of course, put the bulk of the charges upon the motors, the motors should bear their share in proportion to their top-load demand at any given time. Incidentally, if that were adopted, it would very largely meet Mr. Highfield's difficulty; the lighting charges would be lower, though not, of course, as low, as for the power with its larger load factor, but lower than we are in the habit of placing them, and would, therefore, very much assist the small motors supplied through lighting meters. I have been interested in comparing some figures that I got out about six years ago for a small paper which was not published. I there came to the conclusion that for ordinary factory purposes—I do not, of course, refer to motors in large towns, but to factory conditions in factory areas—that it was useless to talk of supplying at 1d. a unit. I think that has been borne out by more recent experience. I know of at least one case where an offer of ¾d. a unit was not considered sufficiently favourable. The private installation in that case was only about 250 k.w. capacity. That was, of course, for factory hours, and in a locality where there was no great objection to installing one's own plant. There was no such question as nuisance to neighbours to be considered.

As to the restricted hour system, that is possibly a little older than Mr. Taylor supposes, even in this country. It was fully seven years ago that the Huddersfield Corporation took on a large consumer at the price of ⅝d. per unit, with the understanding that they were at liberty to cut off the supply for 4 hours daily out of the 24. That gave them a little scope for fog as well as for the evening peak. The only reason that this supply did not continue was, I believe, that the industry came to grief. In the figures that I got out I carefully ascertained—an actual case—the cost of power to a cotton mill in Lancashire. The engine was indicating an average of about 1,300 H.P., and I found that the entire cost including capital charges was 0·231 pence per B.H.P. hour, that is, roughly speaking, about the cost of electrical distribution from a public supply system for average conditions, including, say, the loan of motors and profit to the supply

Mr. Dawbarn.

company, and leaves nothing whatever for the cost of the electric energy. I am only mentioning that figure as showing that it is not possible to distribute electric energy commercially to very large consumers for whom it is practicable to generate their own power. In the Huddersfield case that I mentioned the engineer fully realised the importance of distribution. He entirely got rid of his distribution charges by making it a condition that the consumer should go and set up his works next door, and it was for that reason he was able to supply at the low rate of ⅜d.

The question of batteries has already been dealt with by a previous speaker, but there is one point which I did not understand in reading Mr. Taylor's description of what he proposes to do. He says he would add a "small" dynamo to the motor and a few low voltage cells. I take it that the purpose of that "small" dynamo is to develop the motor load from the cells during the short period when it is necessary to disconnect from the supply main. That being so I do not quite understand why the auxiliary motor can be "small." Why must it not be as large as the 500-volt motor it replaces? Perhaps Mr. Taylor will explain that. On p. 237 he assumes that the motor is only loaded for half to quarter load during the daytime. That is surely assuming a very big margin in the capacity of the individual motors. In Mr. Taylor's scheme we have not only to take into account the cost of maintaining the batteries at a large number of distributing points as compared with one large battery at the generating station, and the cost of these additional motors, but also the fact that at least twice the cell capacity that would suffice at the generating station would be required if distributed. I therefore think these charges would entirely outweigh the extra cost of feeders and plant which would be involved if the peak were allowed to come on to the mains.

Mr. Wright.

Mr. ARTHUR WRIGHT (*communicated*): I think all central station engineers are greatly indebted to Mr. Taylor for the enormous amount of work he has devoted to the very important subject of his paper; also for the lucidity of the many new methods he has adopted dealing with the problems involved. I think the clear way he has shown in Diagram 7, how to determine the stand-by losses under any conditions of load, requires acknowledgment by all of us. In my opinion, the form of graphical analysis adopted for this purpose is entirely sound and extremely useful.

Before dealing with the many new points raised, I think it is a great pity there have been so many miscellaneous definitions (introduced into the discussions on this subject) of load factor, and lately of diversity factor, and I think it would tend towards the greater intelligibility of the discussions, if we could abolish all other load factors than the original one introduced by Colonel Crompton, namely, the ratio of the average use throughout the year to the greatest possible use, had the maximum load been on for 8,760 hours, and also the original definition of the diversity factor, namely, the ratio of the sum of the consumers' maximum loads to the actual maximum load in the year supplied on the feeders of any system. Any other kind of load and diversity factors

departing from this original definition should, in my opinion, be designated by entirely new words, so as to avoid the confusion that is constantly arising. Mr. Wright.

While desiring to refrain from repeating anything I have already said to this Institution on the above subject, I cannot help thinking that this problem of prices for motor load cannot be attacked upon Mr. Taylor's system, without first agreeing whether, in determining the lowest price at which we could supply motive power, which of the three various forms of basing profits, etc. (alluded to in my paper), should be adopted; whether, for instance, prices should be arranged to produce a fixed return on the capital involved, or a fixed percentage on the cost of supplying each unit. In view of the extreme competition for this motive power supply, I am of the opinion that it is sounder to aim at the present time on a fixed return on the capital involved, rather than a fixed percentage on the cost of producing each unit; the increase of business obtained by the addition of the motor load will probably take care of this second point.

I think Mr. Taylor has unnecessarily complicated the treatment of the subject by his departure from the Hopkinson method of treating such stand-by items as management, office expenses, and taxes, in the way he has done on page 229, where, from a particular case investigated, he seems, unless I have mistaken his meaning, to obtain average cost per unit on account of these items to be used elsewhere; whereas it is quite clear no general statement as to future cost on account of such items can be made except in terms of kilowatts, which, in my opinion, enables a much simpler investigation to be used.

I am at issue with the author in his desire to obtain chiefly those motor loads which do not incur material capital expenditure, as stated on page 228. Surely, if a motor business produces a fair return on capital expenditure, say 10 per cent., it is certainly worth having, and the more capital we can get expended with this assurance, the better it must be for everybody concerned. The reason why I think the author is led to over-value this non-interest-paying motor business is that he has under-estimated the enormous diversity factor existing in a large motor business. Instead of the diversity factor being as low as the author assumes, namely, $1\frac{1}{2}$, which is much lower than the diversity factor of the large lighting system in Brighton, I believe that the diversity factor of 2,000 or 3,000 kilowatts of motors distributed in a manufacturing town will be nearer six than it is to the author's limit of four. The reasons which lead me to this contrary opinion are the following:—

The maximum load on a pair of tramway motors frequently reads 60 kilowatts for 30 or more seconds, whereas the average demand on 40 or 50 tramcars comes down to something like 10 kilowatts per car, and over a large system such as that of Glasgow, I am informed by Mr. Lackie that this figure is reduced still further to $7\frac{3}{4}$, showing a possible diversity factor in this case of nearly 8. It may be said that tramway motors in no way represent ordinary stationary motors, but from this I am inclined to differ, as in a manufacturing town, with motors situated

Mr. Wright. all over various works driving tools, sewing-machines, printing-presses, and so on, the conditions of use of the average motor very much more resemble the average use of a tramway motor than it will the ordinary electric pump motor, which, instead of being the most representative class of motor, will turn out to be the most unusual class. As this important question of diversity factor of a motor business is the one which will have the greatest effect in lowering the cost of supplying electricity (on account of its reducing effect on the capital involved), I should like Mr. Taylor to reconsider his figure of 1·5, as on the true value of the diversity factor depends very much whether he is right in assuming that electricity for motive power, unaccompanied by restrictions, cannot pay in the majority of stations at 1d. For reasons already stated, I entirely disagree with the author's statement in the second paragraph on page 245, to the effect that "the station" load factor is obtained by multiplying the "motor" load factor by the "diversity" factor. In my opinion it is entirely a wrong use of the term, and I cannot conceive any relation existing between the diversity factor of a motor business and the station load factor; but this disagreement may be entirely due to my misunderstanding the use made of these terms, and it seems obvious to me that the diversity factor of a large motor business is due to the non-simultaneous use of the motors during the two periods before and after lunch in the working day, and does not have any connection with the number of hours in the year the machinery is at work.

Mr. Gaster. Mr. L. Gaster (*communicated*): I am afraid, speaking from the consumer's point of view, that I cannot quite agree with some of the author's suggestions, owing to the impracticability of carrying them out. The hours suggested at which the current would have to be cut off during the winter months are such that it would reduce the earning capacity of the employed and employer, and particularly in the case of such factories where the price of the goods manufactured is of far higher value than the charges made for power. It would have been advisable to mention some specific cases, indicating the nature of the trades in which the suggested system could be, or has been, successfully employed, as this might form a valuable guide for other central station engineers. From my experience with many trades it is no great inducement to manufacturers to apply electricity for motive power, if they are to be interfered with, or hampered in the proper use of their motors, by restricting the hours of working. Concerning the figures in the table "C," showing the comparative costs per B.H.P. per hour by using gas, oil, or electricity, I should like to point out that too much weight must not be attached to such tables, and they ought to be considered only as very rough approximations, for the reason that the merits of individual installations have to be carefully considered, and the conditions under which the machines are running. From my experience, if electricity could be obtained at 1d. per unit, small factories would adopt the electric motor in preference to gas engines or private small gas plants, and particularly is this the case where a number of scattered engines are required, and where a special

engineer would be needed to attend to the gas plant, whose wages would form a very considerable item on the yearly power bill. One of my clients in London has put up at his factory, first, several gas engines and afterwards electric motors with the idea of running them alternately, but for actual running the motor is preferred, while the gas engines are only kept as a stand-by. In this particular factory the expenses were about equal, electricity being charged at 1d. per unit, but should the charge be increased beyond 1d., the conditions would be reversed, and the driving would be done by gas engines, while the electric motors would be kept as a stand-by. Mr. Gaster.

The question of the use of batteries for private installations has already been alluded to by other speakers as being, in most cases, impracticable, and in this view I quite concur. I have no doubt that there is a wide field open for increasing the motor loads in central stations, but it is essential that canvassing should be carried on by competent men well acquainted with the advantages and disadvantages of the other systems of driving, and capable of discussing their relative merits with the would-be customer. I believe a great deal of harm is done by an indiscriminate condemnation of other systems of driving in trying to push the merits of electric motors without sufficiently considering the requirements of the particular manufacture, but there is no doubt that by a judicious grouping of machines and by a proper distribution of motors a great saving can be obtained.

Mr. S. E. FEDDEN (*communicated*) : I do not consider it necessary to class the motors according to their load factor; they naturally level up all differences themselves. In about 4,000 H.P. connected to my mains I have blowing motors running 100 hours per week; rolling mill motors on and off every half-minute; elevators, etc., and they all level up on the generating plant to about 30 per cent. of the connections, and give a steady load with practically no fluctuations. I do not believe in any complicated or "cut-off peak load" charge. Let your charges be simple and straightforward so that everyone can understand them. In my opinion there is no chance of the lighting load and motor load swamping the power-house, as with the present satisfactory state of generating plant I should feel quite justified in taking the risk of my spare plant being in a condition to run one or two hours per day for two or three months in the winter when the two loads overlap slightly. There is no fear from day fog in a provincial town, where there is a lot of private house lighting, as only a very small proportion of this will come on on the blackest day. In most circumstances I totally disapprove of batteries, on consumers' premises or in substations, as bringing in needless complications. Given a big load and a long load; a sound economical generating plant with overload capacity; reliable mains of big enough sectional area so as not to have too much drop; overground disconnecting boxes or pillars for quickly locating and clearing faults; a simple method of charging; the lowest possible rate per unit for lighting, power, and heating; and the motor (or long) load will soon develop and the stand-by charges practically disappear. Mr. Fedden.

Mr. Cooper. Mr. W. R. COOPER (*communicated*): I notice that the author takes interest and sinking fund at 7 per cent., which is equivalent to a loan for about 21 years, but that depreciation is entirely unprovided for. Considering that the plant is not likely to last so long as 21 years, such an omission is unfair. With regard to putting rent at a zero value, although it may be a small matter, there does not seem to be any good reason for regarding municipal land as worthless. If it is not required it might be sold; on the other hand, if it is required it should be put at its proper value, for if the land is used for a generating station, more land will have to be purchased sooner or later to replace it.

Mr. Boot. Mr. HORACE BOOT (*communicated*): The important question that lighting stations have to settle is at what price can they afford to sell energy during the hours when the station is not loaded up to its full capacity (allowing for proper percentage of spares)?

It is clear that the cost of production during these times should be dependent upon—

(1) The fuel cost per unit.
(2) The oil, water, waste, and stores.
(3) The depreciation and repairs.

All other charges—such as salaries, management, fitters' wages, and running staff—ought to be left out of this cost, because the salaries would have to be paid whether the machinery was running loaded or not.

Some time ago I made careful tests over a considerable period to discover the amount of coal used per unit for additional load. Deducting the lighting-up fuel, and all fuel which would have to be used whether the works were sending out energy or not, that is to say, the fuel used to keep the steam pipes warm, to keep the pumps running, and all radiation losses, I was surprised to find the following:—

The amount of coal used per unit over and above what would be used, provided no load was going out, did not exceed 2·5 lbs. of coal per unit. The comparison was as follows: At a convenient time a portion of the works was kept going, but no energy was being sent out, only the alternators energised, etc., and a direct comparison with the amount of fuel and other stores used was made, when the same boilers were kept at work and sending out energy into the mains, which gave the figures below:—

Fuel	0·26	of 1d. per unit.
Oil	0·042	„ „
Water	0·033	„ „
Repairs	0·067	„ „
Stores	0·007	„ „
Total	0·409	of 1d. per unit.

It is quite clear, therefore, that it would pay (under these circumstances) to sell it at 0·75 of a penny per unit; the conditions would not always be so favourable, and for that reason it would be safer to quote the price of 1d. to 1¼d. per unit.

With regard to Mr. Taylor's remarks differentiating between a motor which is used continuously and a motor which is used intermittently, both motors being used during the hours when *no* additional capital is required to be spent, it appears to me that the same price should be charged, and certainly not the difference he makes, because all energy, no matter for what purpose it is sold, during those hours brings the same percentage of profit to the electricity works. Mr. Boot.

Mr. A. M. TAYLOR (*in reply*): There are four principal points on which the discussion has centred, and I think it will conduce to clearness in most cases, if these points are referred to rather than direct replies given to the various speakers. The four points alluded to are— Mr. Taylor.

(1) Objection to departure from the ordinary methods of treatment.
(2) Criticism of the values taken for the diversity factor and the nomenclature adopted.
(3) Refusal to accept 1d. per unit as a bed-rock price for "interest-paying" loads.
(4) Difficulties suggested in the application of the restricted-hours' system.

In reference to (1), I would suggest that the method of considering things only from the station point of view is apt to lead to an overlooking of what goes on at the consumer's end of the line. My method, on the contrary, works back from the consumer to the station, and is less likely to overlook these points. The outcome of the discussion would seem to show that, through confining investigations principally to the station, the important point has been overlooked of the very low load factor possessed by the average motor (I could adduce a prominent illustration of this); the diversity factor has been hailed as a sort of undeveloped gold-mine, and no explanation has been given of the fact —indeed, I have nowhere seen it observed before—that the station load factor is, with a motor load, occasionally several times that of the motor load factor.

In reply to Mr. Arthur Wright, the principle adopted in the lower half of page 229 of the paper is to split up the present charge per unit for management, etc., into two parts, viz., a part which would be unaffected by taking on a large non-interest-paying load (the station capacity remaining unaltered) and a part (such as the office staff) which would be increased almost in direct proportion to the number of consumers, and hence to their diversity factor. The proportion of present charges which must be so divided up varies, of course, in different towns; but for lighting stations of 2,000 k.w. it should not be materially different from what I have taken, and each engineer can determine it for himself quite readily. In further reply to Mr. Wright, the size of station is assumed constant at 2,000 k.w. all through pages 229 and 230, and the net profit is assumed to be a constant sum per annum.

In reply to Mr. Cooper, I have assumed that cost of land for generating station is included in the sum sanctioned by the L.G.B., on which interest is paid. Depreciation should, it seems to me, be met out of net profit, where it is provided for at all.

Mr. Taylor. In reply to Mr. Vignoles, I have not forgotten the cost of service connections. He will find them alluded to on page 250 of the paper. His figures, too, are greatly over-estimated. I find that 400 (not 5,000) customers of Class I. would account for 5,000,000 units; hence his figures are just twelve times too high. The actual cost of a service connection is about £2, and 7 per cent. on this would be only 3s., which on a £25 bill per annum (5-H.P. motor) is almost negligible. No stiffening of mains has to be considered on a restricted-hour's system, in most cases, hence I allow nothing for this. As regards (2): The diversity factor considered on pages 244 and 245 of the paper is the average value of the *true* diversity factor taken over a period sufficiently long—say for at least an hour—and sufficiently frequent (say at several different times of the week) to ensure a representative average for the class of load in the town. The method adopted in the paper of considering a cylic load factor has, it appears, introduced confusion. This it might be well to avoid by omitting, as far as possible, all reference to any but the "annual" load factor of the motor, or that of the station. In the case considered, the "cyclic" load factor has merely to be multiplied by the ratio of $\frac{49\frac{1}{2}\text{ (hours per week)}}{168\text{ (hours per week)}}$ = say 0·3 in order to convert it to the "annual" load factor. Thus 100 per cent. "cyclic" load-factor becomes 30 per cent. annual; and 25 per cent. "cyclic" becomes $7\frac{1}{2}$ per cent. "annual," as they are designated in Table A.

The statement that the diversity factor is the *reciprocal* of the cyclic motor load factor may then be altered as follows:—

The diversity factor is (in the limit) equal to the reciprocal of the annual motor load factor multiplied by a constant.

An example will make the case clear:—

Taking the motor load-curves just published by Mr. Jeckell,* for Coventry, and working out the diversity factor for each hour of a typical day, by dividing the kilowatts observed at station into the total killowatt capacity of the motors connected (1,150 H.P. × 0·85 = 980 k.w.), we get the following values: 7 a.m. to 8 a.m. = 3·32; 8 a.m. to 9 a.m. = 3·16; 9 a.m. to 10 a.m. = 2·65; 10 a.m. to 11 a.m. = 2·08; 11 a.m. to 12 noon = 2·08; 12 noon to 1 p.m. = 2·20; 1 p.m. to 2 p.m. = 3·63; 2 p.m. to 3 p.m. = 3·44; 3 p.m. to 4 p.m. = 2·04; 4 p.m. to 5 p.m. = 2·0; 5 p.m. to 6 p.m. = 2·25; 6 to 7 p.m. = indeterminate; 7 to 8 p.m. = indeterminate.

The average through the day is 2·62, but the true figure, when all the motors are on (if we eliminate the breakfast, dinner, and tea hours) is nearer 2·1.

Now: Units per B.H.P. installed per hour of working $= \frac{236\text{ units per B.H.P. per qr.}}{\text{say } 13\text{ hrs.} \times 5\frac{1}{2}\text{ days} \times 13\text{ wks.}} = $ 0·254 unit per hour.

(0·3 unit if we take 11 hours per day.)

$$\text{"Cyclic" load-factor} = \frac{0{\cdot}254\text{ unit}}{(1\text{ H.P.} \times 0{\cdot}85) \times 1\text{ hour}} = 0{\cdot}299 = \text{say } 30\text{ p.c.}$$

* *Electrical Engineer*, vol. 35.

Mr. Taylor.

$$\therefore \text{Diversity factor (my method)} = \frac{1}{\frac{30}{100}} = 3.3 \text{ (in the limit).}$$

Hence for a D.F. of 3·3 (in the limit) the *observed* D.F. = 2·1 (with all motors on), and I therefore accept Mr. Arthur Wright's suggestion that in taking 1·5 as the average for a limit of 4·0 I have done injustice to the electric motor. It should be nearer 2·5 for a motor having a $7\frac{1}{2}$ per cent. annual load factor, as per my Class II.

The annual load factor at Coventry works out to about 12·7 per cent. (236 units per B.H.P. installed per quarter).

Now compare the above with Mr. Tapper's figures for Stepney:—

$$\text{Units per B.H.P. installed per hr. of working} = \frac{113 \text{ units per H.P. per qr.}}{\text{say } 13 \text{ hrs.} \times 5\frac{1}{2} \text{ days} \times 13 \text{ wks.}} = 122 \text{ units per hr.}$$

$$\text{“Cyclic” load factor} = \frac{0.122 \text{ unit}}{(1 \text{ H.P.} \times 0.85) \times 1 \text{ hour}} = 0.143 = 14.3 \text{ p.c.}$$

$$\therefore \text{Diversity factor (my method)} = \frac{1}{\frac{14.3}{100}} = 7.0 \text{ (in the limit).}$$

Hence it is easy to understand how it is that Mr. Tapper gets 4·4 for the observed value of his motor diversity factor.

The annual load factor at Stepney works out at 6·1 per cent. (113 units per B.H.P. installed per quarter).

The two above examples, covering largely-different classes of load, appear to me to fully corroborate the deduction that diversity factor varies inversely as load factor of motor. As a further proof I suggest the following considerations:—

In the *traction* examples cited below, the product of diversity factor and motor load factor (annual) and the observed station load factor are given in parallel columns:—

	Theoretical station L.F.*	Observed station L.F.	Motor L.F.	Observed D.F.
	Per cent.	Per cent.	Per cent.	
Wolverhampton ...	34·6	34·4	11·9	2·9
Liverpool	47	$46\frac{1}{2}$	12·5	3·75
Sheffield	37	45	8·8	4·2
Glasgow	40	35	5·7 (?)	7

* Product of motor load factor and diversity factor.

I venture to suggest that these figures bear out the statement which Mr. Arthur Wright disputes, viz., that there is any relation between the

Mr. Taylor. diversity factor of a motor business and the station load factor. I think it has not been sufficiently emphasised in this discussion that it is not the combined diversity factor of motors and lights (taken over a mid-winter "peak" load of at least an hour's duration, so as to take the full overload capacity of the plant) which is the divisor which should be used in obtaining interest charges per killowatt of consumers' maximum demands. The diversity factors of lights and motors during this period are capable of being, and should be, determined separately and used as divisors for obtaining interest charges. I wish to point out that the motor diversity factor will vary considerably according to whether the combined "peak" occurs before or after 5 p.m., and this again will depend on the class of lighting load in the town, whether shops and offices on the one hand or residential on the other.

We all owe a great debt to Mr. Wright for his masterly enunciation of the fundamental principles of economical supply in days when it was not generally understood, and it is a source of much gratification to me to receive from him such an eminently fair criticism on these points, though I regret we seem to agree to differ on the "diversity factor" question. I think he will see, however, that the final sentence of his reply is directly contradicted by the results at Coventry, which were 2·08 before lunch and 2·04 after it.

We now come to (3), and in reply to this, I would say: Nobody has indicated how we are to charge a "bed-rock" price of anything less than the 1·45d. per unit of my Table A. in a small station of 2,000 k.w. capacity, except by a possible reduction of 0·25d. on the works cost. This latter would be justified if the load were *exclusively* a motor load; as, however, there will always be a fair proportion of lights as well, so there will always be a "peak," and stand-by charges will be incurred in boilers and pipework, etc., which would be avoided on the restricted-hours system. It would seem that engineers are, for the most part, counting on the "diversity factor" to reduce their capital costs and stand-by charges. One of the speakers even goes so far as to divide his "stand-by cost" by the aggregate kilowatts of the consumers' motors, and then *again* by the diversity factor, which, in the case concerned, has a value of 4·0. This is equivalent to taking account of the diversity factor twice over and making the stand-by losses per k.w. just four times too cheap! Other engineers, I believe, do the same. What is the result? The lighting consumers have to pay the piper! This is the only way the station is saved from bankruptcy.

The point I wish to emphasise is this: Take a station, as in Class I. of my Table A., where the motor connections aggregate 2,000 k.w., there being no lighting, and the station load is also 2,000 k.w. all day long (nine hours). Surely nobody will deny that here, at least, the diversity factor is unity. On such a station interest charges will come to 0·45d. per unit. If now, instead of this, we take Class II. of motor, and if the diversity factor—which, let us assume for the sake of argument, varies inversely as the motor load factor—were to reach its limiting value of 4, in a station consisting (exclusively) of motors of this class, the interest charges per unit would be the *same* as for Class I.,

excepting that part relating to mains and service connections, the latter of which would, of course, be raised fourfold. But, by however much the diversity factor may be short of the theoretical limiting value at times of maximum load on the station, by that amount will the interest and other stand-by charges (per unit) be *greater* than for Class I.; and it has to be borne in mind that the smaller the average load factor of the motors, the greater is the amount by which the diversity factor falls short of the theoretical limit for the motors only. That this must be so will be apparent when we consider that for a "cyclic" load factor of 100 per cent. the "limiting" and the "observed" values of the diversity factor must coincide, each having a value of unity. Mr. Taylor.

When, in addition to this, we have a lighting load superposed on a motor load, the resultant diversity factor (at the time of peak load) is much less, and the increase of the station load factor is not, I anticipate, in the same proportion as the decrease in the diversity factor (though I have not, as yet, completed investigations on this point). Hence the interest charge where the motor load factor is, say, only 4 per cent., as at Sunderland, will be much nearer 0·75d. per unit than the figure of 0·45d. given by me for Class I., and higher still if we take account of the extra cost for services and mains.

As regards the items for management and office expenses, rates and taxes, etc., it is surely obvious that if diversity factor is inversely proportional to motor load factor, we require four times the office staff for a change from Class I. of Motor to Class II., and hence the "office" charge per k.w. of motors connected is constant, and must *not* be divided by the diversity factor to obtain the annual charge per consumer's kilowatt, while the "office" charge *per unit* will be quadrupled (the station output and load factor remaining as before).

Again, if it be once granted that diversity factor varies inversely with motor load factor, it follows that for a station of a given kilowatt capacity the charge for management and technical staff (including the outside consultant, if there is one) may be divided by the diversity factor to obtain cost per consumer's kilowatt; but the cost per unit remains unchanged, as the aggregate number of units sold, with a change from Class I. of motor to Class II., will be unaltered. Strictly speaking, it will be somewhat increased, as the limiting value of the diversity factor is less closely approached. Similar arguments, applied to rates and taxes and net profit charges, have been duly weighed by me in framing my Table A., in which, I submit, the only uncertain element is my estimate of 1·5 for the diversity factor for Class II., which, in view of the Coventry analysis, I now agree to raise to 2·5. All things considered, I think that the onus of showing how current can be supplied for motive power at a lower rate than 1d. per unit from an average municipal supply station, except on a restricted-hours basis, still rests with my critics and not with myself.

With reference to (4), there are no doubt difficulties in the application of the restricted-hour system, which, however, even in its most unattractive form, seems to have been an unqualified success in Montreal, Brighton, Wednesbury, and numerous smaller towns; and

Mr. Taylor. if we may judge from Mr. Vignoles' remarks, it has been successful at Grimsby in capturing motor loads; while I understand that at St. Pancras, and in the stations of the County of Durham Company, it is also being tried, but with what results I do not know. The question as to whether it will prove a success, or otherwise, seems to me to depend largely, if not entirely, on the prices that can be offered. Hitherto nothing less than 1d. has been offered, but if my figure of 0·54d. per unit (see Table A.) can be justified, the arguments adduced on page 236 of my paper should weigh with factories and other consumers having a good load factor. Where accumulator sub-stations are warranted in a district, these would form a valuable supplement to the restricted-hours system, and practically put it on all fours with an interest-paying load.

According to Mr. Snell, of Sunderland, the capital cost of accumulators and accessories for a sub-station of 2,000-k.w. capacity is only £3 per kilowatt, and the maintenance of the cells under such conditions can be undertaken at 5 per cent. per annum. No doubt there are extra costs in connection with stiffening the mains locally, telephone connections to the main stations, cost of the sub-station building, etc., which will increase this total somewhat, and in the running cost there is the item for wages. All these, however, added together, would probably not amount to more than from 0·1d. to 0·2d. per unit, which would give a figure of 0·65d. to 0·75d. per unit for the total cost. Such a combination would practically place the restricted-hours supply on equal terms with interest-paying motor loads, as far as the convenience of the consumer is concerned, and would, in addition, give the former an advantage of at least 0·25d. to 0·35d. per unit. Such a difference would, in the case of double-shift (continuous) motor loads, be in many cases sufficient to turn the advantage in favour of the electric motor.

The suggestion to use batteries scattered about in small groups on the premises of isolated consumers was made by me to meet the case where sub-stations were not warranted, or where station engineers were not favourably disposed towards their adoption for the purpose of meeting the peak load. It would, of course, be futile, unless means could be devised for protecting the batteries from damage by the ignorance or carelessness of the consumers, and unless the battery-makers themselves were prepared to find the capital for and maintain batteries under such conditions. This, however, I have reasons for believing to be the case. With motors of Class I., a 10-H.P. motor working two shifts could be supplied with current at only 0·12d. per unit above the restricted-hours charge, this figure covering all charges for interest and maintenance of cells, charging dynamo, etc. For a day load, only, the charge would be 0·25d. per unit. It will thus be seen that there is not much to choose between a battery sub-station and private installations of batteries, while the latter offer an incentive to the outlay of private capital and meet the case of scattered consumers in small towns where battery sub-stations would be unjustifiable.

Mr. Gaster asks me to specify some of the uses to which the restricted-hours system can be put. In reply, I have to say that the

Dominion Cotton Mills at Montreal have 3,590 H.P. working on this system, employing motors of 300, 200, 100 H.P., and smaller capacities; the Montreal Steel Works take 175 H.P. in small motors, in 15 to 20 H.P.; the Wire and Cable Company have a 300-H.P. motor; the Oil and Cloth Company, two 200-H.P. motors; the Cement Works, 300-H.P.; and the Water and Power Company, 350 H.P. for pumping purposes. In this country they have at Brighton some 300 H.P. in motors ranging from 30 H.P. downwards, used in breweries, mineral water factories, laundries, printing works, stone polishing and saw mills, ventilating works, etc. An investigation of the average number of units sold per B.H.P. installed per quarter taken over the principal towns of the kingdom will, I believe, be found to show that the average load is only ¼ of the rated load as taken for Class II. of my Table A. It follows that the statements on page 228 of my paper are correct, and that, if continuous loads are in the market, electric-power stations are not obtaining them in any quantity. Until it can be shown that power can be supplied to interest-paying motors at less than 1d. per unit on a sound financial basis, it seems to me that the restricted-hours system supplemented by batteries offers the only prospect to our smaller provincial towns of obtaining such motor loads; and, until these are obtained, bottom prices will never be reached, for the reasons set forth in the paper. **Mr. Taylor.**

In reply to Mr. Jeckell, the fundamental difference between us is that he had obtained his B.H.P.-hours in what I submit is a totally wrong manner. To compare them properly with my Table C. most of his figures have to be divided by four, when it will be found that there is no material difference between his figures and mine. I am sorry that through misunderstanding Mr. Jeckell's verbal question at Birmingham I confirmed him in a wrong impression.

In reply to Mr. Patchell's remarks regarding my Fig. 7, I ought to point out that this will be more intelligible if studied in connection with Figs. 11 and 12 (especially the latter); also with the remarks in the Appendix. No doubt, however, the fault is partly mine in not supplementing for London the explanations I was allowed to give verbally during the reading of the paper in Birmingham.

Mr. Boot's remarks show that my figure of 0·45d. for works costs, on a restricted-hours basis, is about right. But as he does not enter into other costs, I cannot say anything with regard to his suggested selling prices.

In reply to Mr. Dawbarn's remarks, I think this gentleman will concede that if the diversity factor is really inversely proportional to the load factor, the ampere-hour capacity of the private cells would, in the aggregate, be the same as that of batteries in a sub-station, though the maximum rate of discharge would be somewhat higher. The private battery method may be a horribly inefficient way of carrying out extensions into unpopulous districts; but in a similar case, the use of small direct-current boosters for long feeders in 440-volt supply, though equally inefficient, has often saved the refusal of customers where there was not enough demand to warrant a sub-station (whether of the high tension or of the battery type).

The President.

The PRESIDENT: The discussion to-night has reminded me of an old grievance which I have, namely, the load factor. I was under the impression for years that the load factor was the actual energy taken out of a station in comparison with the maximum which that station could provide. That is to say, the load factor of 100 is attained if the real generators of the station, not the auxiliary machinery, are run 24 hours a day all the year round. To-night Mr. Highfield mentioned that the load factor would vary between summer and winter, if you compare the maximum output, say, for 24 hours with the total actual output. Does not that show at once that there is something wrong? The load factor 100 varies. If accidentally a station has a bigger output one day, it depresses its load factor; and if on another day it so happens that there has been a fog all day long, then the load factor goes up enormously and disproportionately. I think the proper way of fixing the load factor is to compare the actual output of a station with the maximum possible output. In a station which has a total of 2,000 kilowatts you take your proportion of the 2,000 kilowatts, but you must not compare your actual load with the chance maximum load at any one time. I really think we ought to apply, perhaps, to the Engineering Standard Committee to clear up that point, and get a satisfactory definition of load factor, especially as there is another factor, the "plant factor," which is being defined as the "load factor" originally was. The discussion to-night has shown that figures are very dangerous things to play with. If you listen to Mr. Jeckell's remarks about Mr. Taylor's figures, and Mr. Taylor's remarks about Mr. Jeckell's figures, you are quite convinced that somebody is wrong. Both sets of figures taken by themselves seem extremely plausible. I think, perhaps, to console Mr. Jeckell a little, if he looks at Mr. Taylor's figures from the point of view of how the proportion works out between electric motors and gas motors, according to Mr. Taylor's figures I think the proportion is even better than Mr. Jeckell's figures. I would suggest to him, therefore, if I may, that the next time a gas man quotes Mr. Taylor's figures about the electric motor he should say, "Very well, but you must also take Mr. Taylor's figures about the gas motor." [Mr. JECKELL: But he will not.] That is where your skill will come in. Certainly Mr. Taylor's paper shows that he has taken immense trouble to get all these figures together. We have had a very interesting discussion, and I ask you now to repeat your thanks to the author for his paper.

The resolution was carried by acclamation.

Proceedings of the Four Hundred and Twenty-seventh Ordinary General Meeting of the Institution of Electrical Engineers, held in the Rooms of the Society of Arts, John Street, Adelphi, on Thursday evening, May 11, 1905—Mr. ALEXANDER SIEMENS, President, in the chair.

The minutes of the Ordinary General Meeting held on May 4th, 1905, were taken as read, and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associates to that of Associate Members—

Percy William Freudemacher. | Bernard Pontet.

Messrs. L. Gaster and F. N. Macey were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

ELECTIONS.

Associate Members.

Gilbert Fox Allom. | George Leask Black.

Students.

Warren Stephen Dyer.
Richard Noel Hanscombe.
Leslie J. Jenkins.
Arnold Lewin.
Frederick Charles William Rogers.
Lancelot Lincoln Telford.
John Weston Wilkinson.

The following paper was read and discussed, and the meeting adjourned at 9.30 p.m.

TELEPHONE TRAFFIC.

By HERBERT LAWS WEBB, Member.

(*Paper read May 11, 1905.*)

A paper on telephony before this Institution is under a certain disadvantage, because it is difficult to tell the earnest telephone men anything about telephony that they do not already know, and it is difficult to tell the non-telephone men anything about telephony that they care to know. In attempting to describe the improvements that have been made in the conduct of telephone traffic and to indicate the relation between traffic efficiency and engineering economy I shall hope at the least to provide a topic for discussion which may interest those members who are not directly engaged in telephony as well as those who are.

I have always held that the study of the traffic is the most important part of a telephone man's work. The chain of reasoning which leads to this conclusion is simple. The sole object of a telephone system is to supply telephonic communication, and telephonic communication consists of hundreds or thousands, or hundreds of thousands, of daily telephone connections. Each connection consists of a certain number of operations, each operation involving a definite performance by apparatus and by a manipulator. Therefore the principal aim of the telephone engineer should be to put the apparatus and the manipulators in a position to execute those various operations with maximum accuracy and celerity. The efficiency—efficiency here meaning accuracy combined with celerity—of the individual connection is the object to be attained, and efficiency of the connection requires efficiency in each step.

Even if the result were solely the supply of the most effective service possible to the public, the accurate and rapid production of the individual connection should be the chief solicitude of the telephone engineer. But the matter goes much deeper than that. It affects the whole engineering design of the system, and it affects both the capital charges and the working costs. Any gain, however slight, in the accuracy or the rapidity of manufacturing the individual telephone connection is felt throughout the whole system. It reduces the size of the plant in proportion to output and so reduces capital charges, and it reduces the amount of work done in proportion to output and so reduce working costs.

I have read somewhere a remark, attributed to a famous member of this Institution, which aptly illustrates the point. Sitting on a moun-

tain side, he said—"I let fall this grain of sand, and the whole earth feels the shock." Telephone men might well use this as a text. If in a telephone system, where hundreds of thousands, sometimes even millions of operations are performed daily, we make any one of those oft-repeated operations more accurate or more rapid, the whole system feels the effect. The gain of a second, or of a fraction of a second, on an operation many times repeated each day, has, in a large telephone system, a cash value running into handsome figures.

The importance of the study of telephone traffic, then, cannot be over-estimated, and it is clear that the efforts of all who are engaged in the design and conduct of telephone systems are ultimately focussed on the production of accurate and rapid telephone connections. There are many different functions to be performed in a modern telephone system, as there are in a modern battleship; but the true function of the battleship is straight and rapid shooting, and the true function of the telephone system is straight and rapid operating. The cook of the battleship does his share in straight and rapid shooting by keeping the gunners' digestions in order, and in the telephone system even the humble wayleave officer or the storekeeper has his indirect share in the production of accurate and rapid operating.

The improvements in telephone exchange apparatus during the past ten years have been revolutionary. The history of telephone exchange working, covering now about twenty-five years, may be roughly divided into two periods: one of about sixteen years, in which the apparatus was mainly experimental, and many different systems were tried, but none was produced capable of dealing with a large daily traffic with real accuracy and rapidity; and one of about eight years, in which there has been perfected and standardized apparatus, largely automatic in its working, capable of the greatest accuracy and rapidity in operation. In the old apparatus the percentage of error was very great, owing to the distances between the signals and the jacks and plugs they were related to, and owing to lack of definiteness in some of the signals—on many occasions they worked at the wrong time, and on others they failed to work when required to. With regard to rapidity of operating, the old apparatus was relatively slow in working for a variety of reasons. The distance between the signals and the jacks and plugs imposed a certain strain on the operator's attention and memory, the replacement of signals occupied time, and the lack of definiteness of some of the signals and the total absence of some essential signals necessitated a certain amount of supervision of each connection by one or more operators to ensure a reasonably accurate and satisfactory service.

In the standard apparatus of to-day all these conditions have been changed. The use of lamp signals enables many things to be done which were impossible before. The prime advantages of lamp signals are that they are extremely compact, they have no working parts, and therefore may be placed in any position, vertical, horizontal, or at an angle; they are automatic in action or self-effacing, since the signal disappears immediately the current is cut off; and finally, they give a

much more positive and assertive signal than any form of indicator. These various qualities enable several radical improvements to be made. The signals are placed immediately adjacent to the jacks or cords they control, which, in large switchboards, is impossible with electro-magnetic indicators; the line lamp is immediately above or below its corresponding answering-jack and the supervisory lamps are

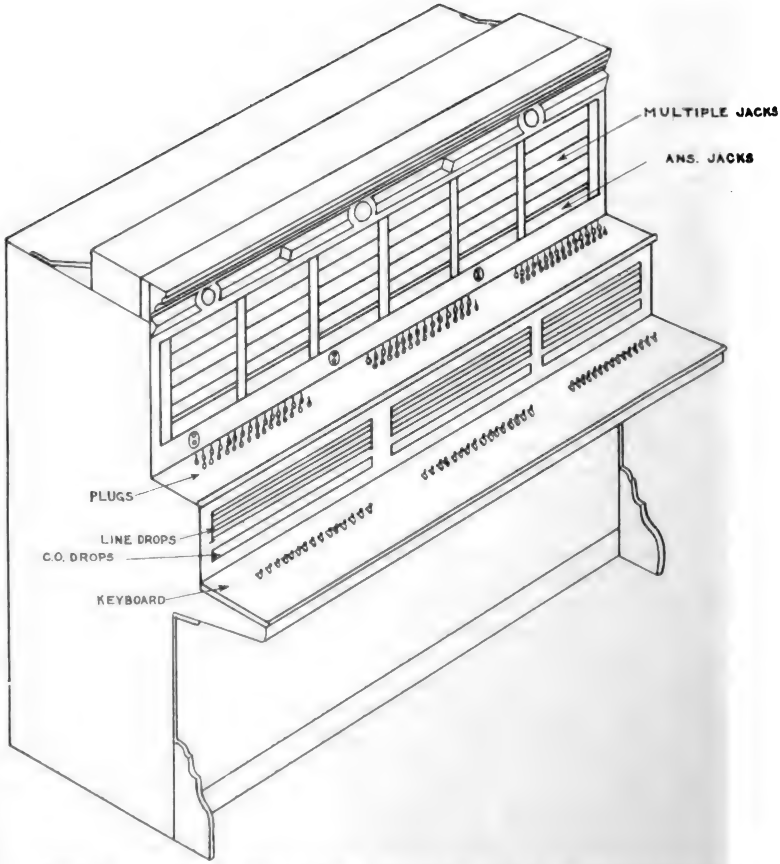


FIG. 1.—Series Magneto Board. Drops restored by hand and placed in separate part of board from jacks and cords.

in line with the connecting cords and close to them. With this arrangement the operator loses no time and has to exert no brain-power in tracing the relation between the signal and its corresponding jack or cord. The difference in effect between the modern arrangement of directly associating the signals with their corresponding jacks and cords and the old arrangement of placing the signals in a separate part of the board from that occupied by the jacks and cords is some-

thing akin to the difference between a telegram in plain language and one in code. In the one case the meaning of the signal flashes instantly to the brain of the operator, and in the other case a certain effort, and a certain interval of time, are required for translating the meaning of the signal. The automatic working of lamp signals is of much wider range than that of electro-magnetic signals. We had self-

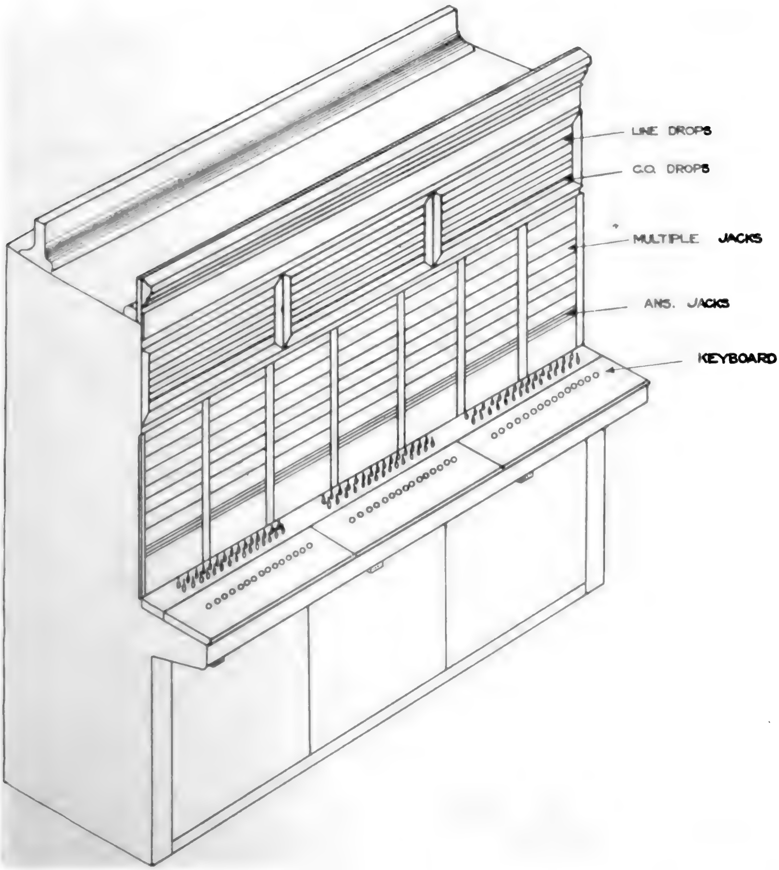


FIG. 2.—Bridging Magneto Board. Self-restoring drops, but still placed apart from jacks and cords which they control.

effacing, or automatically restored, indicators before lamp signals were introduced. But the self-restoring indicator had but two positions—only two words in its vocabulary, so to speak. The lamp signal has several; it may be alight or out, corresponding to the down and up positions of the indicator, but it may also flash, and it may be made to flash at different rates of speed, easily recognisable. Therefore, apart altogether from the fact that it is much more easy to apply to lamps

distinctive marks indicating different classes of service than it is to apply such marks to indicators, the lamp signal is able to convey a greater number of meanings as a working signal than an indicator. Finally, the more assertive and positive signal given by a lamp as compared with an indicator is due to a simple physical fact—the great sensitiveness of the eye to light. The glowing of a lamp signal

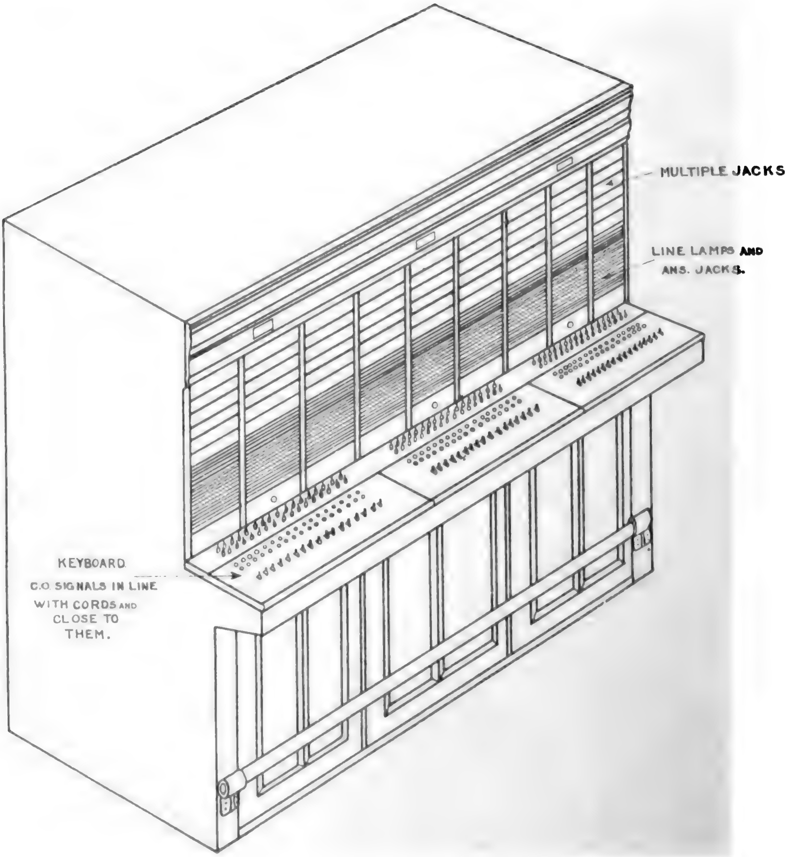


FIG. 3.—Relay Board. Automatic lamp signals placed immediately adjacent to jacks and cords which they control.

instantly attracts attention, no matter at what angle the lamp may be relative to the eye, and in many cases the lamp is seen instantaneously where a fallen drop would be unnoticed for several seconds. The lamp is seen out of the corner of the eye, so to speak, whereas an indicator must be more directly in the range of vision. The diagrams, Figs. 1, 2, and 3, illustrate the relative positions of the signals and jacks in the three chief types of multiple switchboard.

Perhaps the most striking improvement in operating resulting from the use of lamp signals and the supply of energy from a central source is automatic supervision. In the older systems of working, as has already been said, the indefiniteness and unreliability of the signals made it necessary, in order to reduce as far as possible the percentage of error, that the operator should give each connection a certain amount of supervision. This supervision was directed to ascertaining that the two subscribers had got together all right, and later, in the many cases where the disconnection signal was not given, of ascertaining whether the subscribers had finished talking and the lines could be disconnected. This supervision demanded a certain amount of the operator's time on each connection in excess of the time actually required for the operation of the connection. In the modern switchboard the exact condition of the two subscribers' lines connected is shown by the state of the two supervisory lamps associated with the connecting cords. By the automatic working of these two signals the operator knows when the called subscriber answers, she knows when one subscriber hangs up and the other does not; she knows if either subscriber wants her to come in on the line, and finally she knows when the two have hung up. The operator sees these various conditions of the line by the action of the two lamps, and she requires to do no direct supervision. If either subscriber desires to attract her attention he flashes one of the supervisory lamps, by moving his switch-hook up and down, and it is only on this signal that the operator goes into the circuit. The automatic supervision and the automatic and definite disconnection signal afforded by the double supervisory signals constitute an immense advance in the means of handling telephone traffic.

In the working of junction lines—a branch of the operating which is of the highest importance in large systems, since the greater proportion of the traffic passes over the junctions—great improvements have been effected by modern apparatus and methods. The use of lamp signals affords what was lacking before, a positive disconnection signal at the incoming end of the junction. The absence of such a signal was formerly responsible for many operating errors and for much extra work and waste of time. The existence of the supervisory lamp on the cord at the answering position enables the incoming junction operator to signal back automatically to the answering operator if the line wanted is engaged or out of order.

In the accompanying diagrams the average time occupied in the various steps of a connection between one direct line and another is shown for magneto working and for working with modern standard equipment.

The explanation of the diagrams is as follows:—

Zero being the starting-point at which the subscriber rings or takes his telephone off the hook, A is the point at which the operator has plugged in and answered, B the point at which she has taken and repeated the number, C the point at which she has tested the line wanted, plugged in and started to ring, and D the point at which the

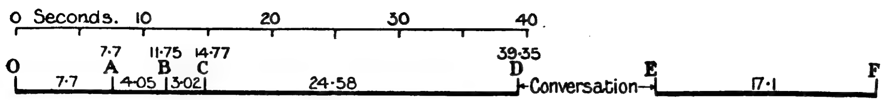


FIG. 4.—Progress of Local Connection, Magneto System.

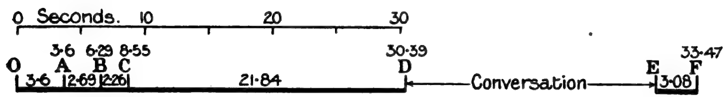


FIG. 5.—Progress of Local Connection, Relay System.

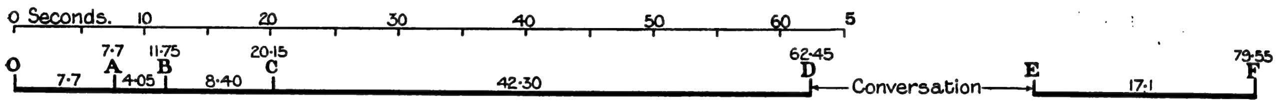


FIG. 6.—Progress of Junction Connection, Magneto System.

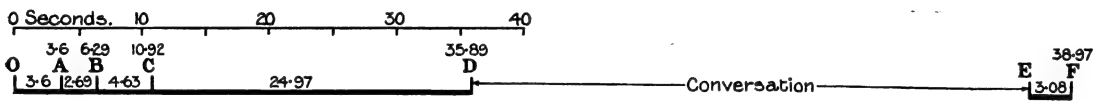


FIG. 7.—Progress of Junction Connection, Relay System.

O Beginning of call. Subscriber rings (Magneto) or takes down Telephone (Relay).
A Operator plugs in and answers.
B Operator takes number and repeats it.
C Operator tests line called for, plugs in and starts ringing.
In Junction Connections step B–C includes assignment of Junction by Junction Operator, plugging into Junction by Answering Operator, and testing, plugging in and starting ringing by Junction Operator.
D Called Subscriber answers.
E End of Conversation (duration of conversation is not shown to scale).
F Operator takes connection down.

called subscriber answers. From D to E is the conversation, which is not shown on the diagrams, and F indicates the point at which the lines are disconnected after the end of the conversation at E. It will be seen that the total time spent in operating a local connection with magneto working was 14·77 seconds from the beginning of the call to the moment when the operator began to ring the called subscriber, and 17·1 seconds from the end of the conversation to the moment when the operator disconnected the two cords. In the diagrams relating to junction calls the step B–C includes the time occupied by the answering operator in speaking by call-wire to the junction operator and getting from her assignment of a junction and in plugging into the junction, and the time occupied by the junction operator in testing the line called for, plugging in and starting to ring; during the step B–C on junction connections work is being done simultaneously by the two operators at either end of the junction line.

There are several noticeable points in these diagrams. I should say first of all that the times given are the averages of many thousands of stop-watch observations made by trained observers with special signalling appliances attached to the lines under observation, and the figures indicate with great accuracy the actual average service received by the public. The service observed is that of New York city, where the working was at one time uniformly magneto, though with various types of equipment at different central offices, and is now and has been for the past three years uniformly relay, or common battery, with practically identical equipment at all central offices.

Taking the magneto service, the average time of disconnection, 17·1 seconds, seems long. The explanation is that on many occasions no disconnection signal was received by the operator, either because the subscribers failed to "ring-off," or because the signal failed to work. In such cases the operator would only learn that conversation had actually finished by supervision—listening-in. Such a measure being necessary on a large proportion of connections, a high average figure for the disconnection necessarily resulted. Similar conditions would be found on any magneto system to-day where the subscribers have not been rigorously trained to "ring-off."

A curious feature of the service with magneto working is the much longer time taken to complete junction connections, and the diagrams show that the called subscriber's answer was apparently eighteen seconds slower on junction than on local connections. As a matter of fact the diagrams do the called subscriber a slight injustice; he really answers the call somewhat more quickly than the diagrams show. The explanation is that the operations on each connection are not strictly consecutive, as an operator usually deals with several connections at once. This results in breaking the strict continuity of the operations on a given connection; there occur short gaps in the train of operations on each connection, during which intervals operations on other connections are being performed. For the sake of clearness I have not attempted to illustrate this interweaving of operations, but have shown the various steps as if they were performed

always consecutively. The natural tendency of operators is to complete local connections first; this slightly increases the gaps in handling trunk connections, and so makes the total time of operating, and apparent time of subscriber's answer, longer on junction connections.

The really striking features of the diagrams, however, are the great improvements in efficiency resulting from uniform relay working. It is seen that the local connection is operated in 8·55 seconds, as against 14·77 seconds, and the junction connection in 10·92 seconds as against 20·15 seconds, while the delay in disconnection is reduced from 17·1 seconds to 3·08 seconds, a substantial and important gain due entirely to the use of double supervisory signals.

To show more clearly the gain in efficiency of operating with modern apparatus I have plotted in Figs. 8 and 9, the total time occupied in operating each class of connection under magneto and relay working, including supervision and allowing five seconds for ringing, but eliminating the called subscriber's delay in answering, and, of course, the conversation. These diagrams show a very striking contrast between the results under old and modern methods. It is seen that the time spent in operating the average connection with standard apparatus is just a third of the time occupied with magneto apparatus; in junction connections the gain is even greater, the time spent in operating the average connection with standard apparatus being less than a quarter the average time with magneto apparatus.

These figures indicate that with the apparatus of to-day the operator should be able to do from three to four times the amount of useful work, that is, handle from three to four times the number of calls in a day that she was able to cope with ten or twelve years ago. It is impossible to give quantitative results of any exactitude, for a variety of reasons. The nature of the telephone call itself varies in different places; in some places there is hardly any junction work and the business is nearly all flat rate, making the average connection a very simple operation, while in other places there is much junction work, and a large proportion of the traffic consists of message rate calls, party line calls, call-office calls, and suburban and long distance calls, which all have their quota of complication and extra work. Moreover, with the great increase in the use of the telephone during the past ten years there has arisen a corresponding increase in the fluctuation of the traffic—the busy hour is busier, the sudden rushes are more frequent and more accentuated—and it is the busy hour which, to a great extent, regulates the day's work of the operator in large exchanges, and the day's work of the junction line in large systems.

For all these reasons it is impossible to establish exact comparisons of quantitative results to prove that the whole gain in efficiency and economy indicated by these diagrams has really been utilised. That a large part has is unquestionable. One instance that has come under my notice, illustrating a very substantial gain in economy, may be

mentioned; it is an exchange which formerly contained a magneto equipment for 5,200 lines. The present switchboard equipment of standard apparatus is contained in a room of exactly the same size as the former room, indeed, built over it, and has a capacity of 9,600 lines. To show how difficult it is to make exact comparisons, I may mention that in the present switchboard the answering positions occupy about three-quarters of the space formerly occupied by the answering positions of the old board, whereas the incoming junction positions, though they are more economical, occupy more than twice the space formerly required for incoming junctions, so great has been the increase in the amount of junction traffic.

A saving in time in operating the average connection results in a more economical use of the plant in two ways: first, as the operator can handle more traffic in a day more lines can be terminated at a position, which means, as I have just indicated, a shorter switchboard for a given number of lines, with many attendant economies; and second, as the plant is used for a less amount of time on each average connection, the daily traffic-carrying capacity of the plant is increased. This has a direct effect on the economy of a very important part of any large system—the junction lines and their necessary switchboard equipment. It has also an effect in reducing the "engaged" trouble—that bugbear of all busy telephone systems. In Fig. 9 the diagrams illustrate the total time that the plant is employed in the unproductive part of the connection, the time that the plant is in use from the call to the second subscriber's answer, and from the end of the conversation to the disconnection. It will be seen that on the local connection the operating period on each connection has been reduced from 56·45 seconds to 33·47 seconds, a gain of 22·98 seconds, and from 79·55 to 38·97, a gain of 40·58 seconds on junction connections. Allowing an average of 120 seconds for the conversation, the result of shortening the time during which the plant is tied up on each connection by 40 seconds is an increase of 25 per cent. in the traffic-carrying capacity of the junction plant.

Importance of Traffic Study.

It must not be imagined that the great increase of efficiency shown by these diagrams is due solely and entirely to improved methods of signalling and improved apparatus generally. It is also due to more efficient operating and a more thorough study of the minutest details involved in the handling of telephone traffic. It remains true, however, that the improved apparatus is the fundamental cause of the increased efficiency, for with the standard apparatus of to-day we not only get signals having definite meanings, and so eliminate a fundamental defect from telephone switchboards, but we get absolute uniformity of working, and so are able to train operators more effectively and more systematically. We give the operators better tools to work with, tools which involve less mental labour and less physical labour, and we are able better to teach the operators how to use those

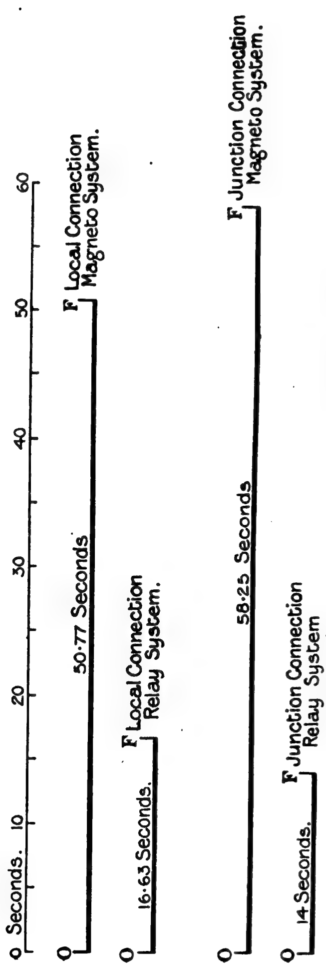


FIG. 8.—Total Operating Time per connection, including supervision and ringing. Junctions in Relay System have Automatic Ringing.

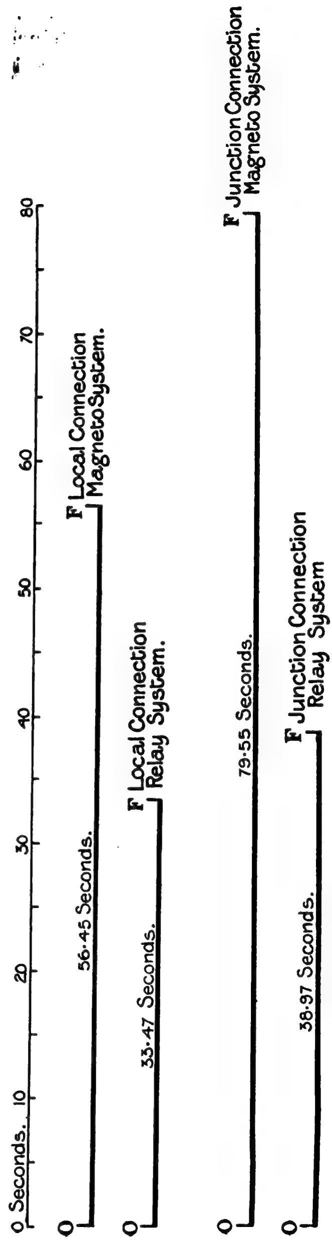


FIG. 9.—Total Time Plant is in use per Connection, exclusive of Conversation.

tools most effectively, both because the whole group of apparatus has become more scientific, and because the study of all the features of telephone traffic has become more scientific. The gain in efficiency of the telephone connection would be much less than it is if the introduction of accurate and automatic apparatus had not been accompanied by the adoption of systematic methods of instructing and training operators, of supervising their work and of continuously observing and testing the service. The preliminary training of operators is a most important point in a large and complicated system. In the old days, with a variety of types of equipment in use in the different exchanges, it was impracticable to establish a really effective training school. To-day, with uniform equipment in all exchanges, a training school where the embryo operator learns her work by the practical manipulation of the same appliances as she will handle in the regular exchange is a most natural institution. At such a training school more progress is made in a month in turning out an efficient operator than was formerly made in three months by the method of letting learners listen-in at a working position and gradually pick up the work by experiment. In any large system a training school is absolutely necessary for teaching operators the general methods of the work, the proper terms to use, the geography of the exchange districts, and so forth, but the course is relatively ineffective unless it includes practice with the actual appliances the operators are to handle, and practice in answering and completing calls; thorough practice of this kind is difficult to give unless the exchanges have a uniform type of equipment.

The general supervision of the service becomes much more effective with standard apparatus, because the lamp signals are much more easily observable by the supervisors than indicators are. Standing behind the operators at a relay switchboard one can practically follow every movement of the subscribers' telephones; a line signal unanswered or a pair of supervisory signals unattended to glare insistently until the operations demanded are performed. The supervisor's attention is instantly called to any unusual rush of calls, to any difficulty or delay.

The constant observation of the traffic is the measure which has contributed most to the effective use of modern apparatus, and to the attainment of a high standard of efficiency and accuracy in the operation of a large daily volume of telephone traffic. It is only by making continuous tests on a certain proportion of the daily traffic, noting not only the time of every step, but the method and manner of conducting every part of the operation, that sufficient information can be gained of operations involving so much detail to enable defective methods of operating to be eliminated or checked, and suggestions to be evolved tending to a general increase of efficiency.

Some idea of the complexity of telephone traffic may be had from the fact that the form for recording these service observations contains forty-two columns, each with its appropriate heading. An entry in each of these columns would not be made for a single call, but the test

of one connection might require notes in a fair proportion of the columns, and even if but very few entries are made, each test or series of observations contributes its quota of information relative to the speed, the accuracy, and the general efficiency of the service. To set all these observations out on a diagram would hardly be interesting, and I will only say that the observations give the time, in seconds and fifths, of every step of the connection, the result of every connection, whether effective or ineffective, and if ineffective from what cause—engaged, don't answer, cut-off, wrong number, subscriber left instrument, etc. —the mistakes and omissions of the operator or the subscriber, for even telephone subscribers are known sometimes to make mistakes—and in short, every ordinary vicissitude that the telephone connection is subject to. The information gained by a large number of tests of this kind, in which observation is made of every detail in the brief history of the telephone connection, is of enormous value in bringing to light the weak spots in the service, whether they be due to defects or faults in the plant, to slowness, inattention, lack of co-operation or lack of method, or erroneous methods on the part of the operators. I hardly like to hint that there may be sometimes lack of method or erroneous methods on the part of the users of the service, who may thus contribute to the errors and delays which sometimes occur in the daily stream of telephone traffic; but if there be, continuous service observations will reveal them, and measures may then be taken to suggest such reforms as seem advisable.

To secure speedy and accurate operation of the vast volume of traffic which flows daily through a large telephone system requires first, that the apparatus used have signals of definite meaning, that the working of the apparatus be largely automatic, and that the apparatus be of uniform type throughout the system; second, that the operators be thoroughly trained in the manipulation of the apparatus and in the methods of dealing with all varieties of calls before being entrusted with the conduct of actual traffic; third, that the operators be continuously trained to active co-operation with each other, so as to produce general efficiency, and to accuracy and method in every detail; fourth, that a constant study be maintained of the actual conduct of the traffic, directed to the improvement of the standards of accuracy and speed.

Mr. Gavey.

Mr. J. GAVEY: There are several gentlemen here who are much more closely in touch than I am with the actual details of traffic such as are illustrated in the paper and the diagrams, so that, with your permission, I propose to refer more particularly to the relative capital expenditure and working expenses when comparing an old type of switchboard with a modern well-designed and up-to-date exchange. To do this, I propose briefly to refer to the elementary operations involved in placing two subscribers in communication, first on an ordinary magneto exchange, and secondly on an automatic signalling exchange, one of which has been described by the author as a relay board. A subscriber on a magneto exchange first calls attention by

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turning the handle of a small magneto generator. At the exchange, a shutter, generally placed at the top of the switchboard, falls, and the operator goes through the mental process of connecting in her mind the position of the shutter and the corresponding position of the jack on which the calling subscriber's line is terminated. This done, she plugs in and says "Number, please." She then tests the line of the wanted subscriber and rings him up, probably waiting in circuit for a brief period to see if he answers; if not, she turns her attention to another call; then comes in circuit on the first line and rings up again. If the subscriber does not answer speedily, she may have to do this on two or three occasions, thus wasting a lot of her time, because she has no other means of ascertaining whether the two subscribers are in communication except by listening to their talk. Again, there is the question of the clearing-out signal. When the conversation is over the subscribers have to ring off; a shutter in the cord circuit is dropped, and the operator then severs the connection; but as so many subscribers fail to ring off she has to come in circuit when any given two lines have been engaged for a lengthy period to ascertain whether the subscribers have finished their talk. Thus, in the course of a day's work a great deal of time is wasted. On the other hand, with the automatic signalling, the operator knows absolutely, by glancing at the signals, whatever is going on. She answers the call, which is indicated by a lamp close to the corresponding jack, she plugs in without hesitation, tests the line, gives a brief ring, and goes on with her other business; the supervisory lamp on the wanted subscriber's side is lighted, and it remains lighted as long as the subscriber does not answer. From time to time the operator gives a brief ring, but she does not waste her time by coming in circuit, she goes on with the remainder of her business. In the same way, when the conversation is finished, the mere hanging up of the telephones lights at the extremities of the circuits the two supervisory lamps, and that is an absolute order to disconnect. The difference in the two systems results in this. Unquestionably one operator, with a suitably designed automatic signalling system, can work double the number of subscribers that she can on a magneto system. Consider what that means. The cost of a section in a large multiple board with, say, 12,000 or 14,000 subscribers on it, may run to something like £1,000. If the design of a board admits of one operator doing twice the amount of work, she does more than make two blades of grass grow where one did before, because a saving of £1,000 is effected on every section: there is the saving on the floor space—a very material item in a modern city—and the saving in the operating expenses, because it is possible to work a large exchange with half the number of operators. Then, again, that is not the sole measure of economy. Some reference has been made to the economy in working junction circuits. In a large exchange system, like that in London, from 20 per cent. to 25 per cent. of the total number of lines used are devoted to junction purposes; in other words, there is one junction line for, say, every four subscribers; and as the junction lines are much longer as a rule than the subscribers' lines, it may be assumed that 30 per cent., perhaps, as a rough figure, of

Mr. Gavey. the total mileage of such an exchange system is devoted to junction purposes. Mr. Webb, in his paper, shows that the junction connection through a magneto system occupies 79·59 secs. as against 38·97 secs. on a relay system. If 30 per cent. or 40 per cent. of the capital is invested in junction lines, and if a saving, say, of 15 per cent. of the total capital expenditure on copper buried in the streets can be effected, a remarkable measure of economy is achieved. Therefore a properly designed system means that the ideal conditions are obtained, viz.: great economy, and, as shown by these figures, greatly improved efficiency.

Mr. Cook. Mr. W. W. COOK: Mr. Webb has enumerated the various improvements which have contributed to and resulted in the excellence of the modern telephone switchboard; but I do not think he has brought out clearly the relative importance of those improvements. In my opinion the real dividing line between the periods mentioned is the introduction of double supervisory signals. I am quite sure that Mr. Webb himself appreciates the importance of this point, but I am afraid that the casual reader of the paper might imagine that this was in some way the result of the introduction of lamp signals, and could not have been attained without their aid, and in support of this view the beginning of the first paragraph on page 295 might be quoted. The word "perhaps" might have been omitted, but I think the misleading sentence is "resulting from the use of lamp signals, etc." It is quite true that the double supervisory system came after the introduction of lamp signals, but I submit there is no necessary connection between the two, and that the double supervisory signal is the all-important fact. I do not wish in any way to minimise the importance of lamp signals; owing to that quality which Mr. Webb happily describes as their assertiveness, their reliability, and their compactness, they are indispensable in large switchboards where heavy traffic has to be dealt with; but in discussing principles I think a distinction ought to be drawn between signals and indicators. The distinction, which is somewhat arbitrary but fairly well recognised, is that an indicator cannot be under continuous control from one source. It may be dropped or it may be restored, but only after some other agency has put it in a position to respond to the next action. A signal, on the other hand, is actuated by a current in the same way as an indicator or a lamp, but like the lamp and unlike the indicator it automatically regains its normal position directly the current ceases. The advantage the lamp or the signal has over the indicator is that either of them can show continuously the state of affairs, while the indicator can only show that certain acts have been done, and this is only true when the two parties, *i.e.*, the subscriber and the operator, acting independently and with imperfect knowledge of the other's doings, both work in harmony. This continuous knowledge is not, however, the whole secret of the effectiveness of the modern supervisory signals; what is wanted is that an operator shall have independent and continuous knowledge of what is happening on each side of the cord circuit, and this is what is attained by and only attained by the double supervisory signal. The weakness of the ring-off indicator was not, as might be imagined from the paper, due to the fact that

it failed to work when required. It was, and still is, a very reliable piece of apparatus, but there are three reasons why it was not satisfactory. One, and the most important, was that it had to be worked by the subscriber, who had to perform a deliberate act that had no necessary connection with the work in hand. Secondly, it did not give continuous supervision; and, thirdly, it did not give independent knowledge of the state of each side of the circuit. A great many attempts were made to obviate these disadvantages, but one or other was always retained until the common battery system was evolved, and it is really astonishing that even now systems are defended and even advocated which infringe one or more of these conditions. The real aim of course is to enable the operator effectively to supervise without listening in at all, and a system is good or bad according to how far this is effected. I have some New York figures on this question of listening in which are very instructive, and might very well have been included in the paper. Under the magneto system, in both local and junction calls, an operator had to go into circuit on an average five and half times. The time occupied in so doing in the case of a local call was 14 secs., and in the case of a junction call 16 secs. With the introduction of the common battery system this disappeared entirely, and not only is the time saved, but what is more, the integrity of the connection is preserved. Claims are often made for systems that an operator cannot possibly listen in. Even if this claim were well founded, as it is not, it would be attained at the expense of good service, but really the best method of ensuring that an operator will not listen in is to obviate the necessity for it. An operator must listen in unless the signals tell her exactly what is happening without doing so, and if you do not provide her with proper means of doing it she will find other means. Mr. Cook.

The present system of supervisory signals meets the conditions I have mentioned almost perfectly, and, if it were worth while, they could be made still more perfect by the addition of a third lamp which would only come into play when the subscriber replied. The only possible uncertainty now is whether the calling lamp being alight means the subscriber has not replied or whether he has answered and gone away; but in practice the operator has no difficulty in distinguishing between the two.

Mr. J. E. KINGSBURY: I should like to join those who have preceded me in thanking the author for bringing this subject before the Institution. I think it would not be possible to emphasise more than he has already done the importance of traffic study in designing and arranging telephonic apparatus. It may be well to consider for one moment what the extent of that traffic is. The word "traffic" usually implies some element of bustle and noise, something that can be seen and heard. The Thames, when it was used for local traffic, was called "the silent highway." It may seem something of a "bull" to describe a telephone line carrying conversation as a "silent" highway, but it is so except to the two people who are talking. I estimate that, in the ordinary way of counting messages, there must be some five million Mr. Kingsbury.

Mr. Kingsbury.

messages daily transmitted over those silent highways in the United Kingdom. It is obvious that the organising of that traffic for the greatest convenience of the subscribers and for the highest economy in service must need an immense amount of study. Mr. Webb has drawn our attention to the importance of that study. Perhaps it might seem that he has not gone quite far enough in directing the course of the study. To some extent he may remind us of having suggested the importance of the study of diet without having indicated the sort of diet that we should indulge in. I have no doubt Mr. Webb would tell me in reply that that is because different constitutions require different diet, and that is true. There is probably no telephonic service which is exactly like any other telephonic service. Each requires to be studied on its merits. But there are, at the same time, certain broad lines covering all to which reference might have been made. A point of economy already referred to by Mr. Gavey may be emphasised in regard to the switchboard by stating that, except the line circuit, everything on the switchboard depends upon the traffic. The only fixed item is the apparatus connected to the lines, which must be there whether the traffic is large or small. If the traffic is large or ill-regulated, all the rest of the switchboard must be more costly. If the study is carefully carried out, and the best results obtained from it, then the economy of the switchboard apparatus may be largely augmented. That, of course, is perfectly clearly understood by all telephone engineers concerned with large systems. The traffic is forced upon their notice; though unseen by the public, it is very much in evidence to them; and that is one of the points, as Mr. Webb has stated in his paper, which it is difficult to bring before them as something new. But it is not all telephone engineers who have a large system under their control, and who have an opportunity of extensive study of traffic problems. To them I am sure Mr. Webb's paper will be of considerable value, and they will be enabled to utilise in the development of their systems much that he has brought before our notice.

If I am not taking up your time unduly, there are one or two points on the evolution of the switchboard I should like to refer to. Mr. Webb has laid stress upon the value of the answering jack being adjacent to the lamp signal. That is unquestionable; it is an enormous advantage, but I should like at the same time to point out that it is not a modern discovery. Before any of the types of switchboard which have been shown here were in existence, it was not unusual to place the jack—there was only one jack in those days—quite close to the indicator. It was only altered because of the mechanical conditions. It was obviously impossible to have numerous cords crossing and recrossing the indicator field. So long as the indicator was a mechanical indicator it was not possible to place the jack and the indicator close together on a large switchboard. When, however, the indicator was divided into two parts, advantage being taken of the electrical long arm to let a lamp replace merely the shutter portion, the mechanical features could be placed somewhere else. In this way

a large space on the face of the switchboard was available for operating, and the distinct benefit of the jack and the signal being close together could be taken advantage of. There are several other points in the paper to which reference might be made, but there are many present here this evening who have made a special study of telephone traffic problems, whose remarks we should like to hear. Mr. Kingsbury.

Mr. S. J. GODDARD: I wish to associate myself with Mr. Kingsbury in what he has said in regard to the paper. Mr. Webb has told us a good deal about the switchboards, but he has not told us so much about the traffic as he could have done, and as we wish he had done. I take it the problem the telephone engineer has to face is very much the same as that which the railway engineer has to face: he has to make arrangements for taking the largest volume of traffic from one place to another at the smallest cost, in the shortest time, with the greatest efficiency, and with the least waste; and this can only be done by constant study of the traffic in its ever-varying phases. I am going to suggest, if I may, four points to which special attention should be directed. First, the number of calls made by the individual subscriber. Unless we have this information, and accurately, it is impossible to distribute the work amongst the operators as it should be distributed, so as to keep them all busy at the busiest time, and at the same time prevent any operator being overloaded at any time. The second point is the variation of traffic during the hours of the day. It is only by studying this that it is possible to have an adequate operating staff when your traffic demands it. The third point is the study of the junction traffic. It is of the utmost importance that there should always be a supply of junctions available for all emergencies, and unless we are constantly studying the way the junction traffic flows we may be landed at some time in the position of having a lot of traffic, and not having the means of carrying it. It is necessary, from time to time, to form an intelligent anticipation of how the traffic is going to develop, so that we may be able to provide the requisite junction circuits to carry the traffic when it arises. The fourth question is the methods of dealing with the calls by operators and subscribers. It is only by constantly observing the operators' methods that we are able to locate their faults, and get the operators into the best methods of handling the traffic. Incidentally a close observation of the operating enables us to try to induce subscribers to comply with the rules (which they often do not do) to use their telephones, their voices, and to moderate their language in such a way as will not break down the operating. There is another point in connection with the traffic question which is of extreme importance, *i.e.*, the great difficulty which occurs in actually counting the calls made and following them through to their destination. You can count trucks as they go by on a railway, but if you count calls as they come over a telephone system hour by hour you are very apt to dislocate the traffic entirely. The National Telephone Company pass over the London system every day something like half a million calls, and any inquiry that is made, unless it is done very carefully, will tend to dislocate some portion of the traffic, with a Mr. Goddard.

Mr. Goddard. disastrous result. So that before the telephone engineer can study the traffic, he has first to study the means by which he can arrive at the facts on which he is going to base his conclusions.

Mr. Kennedy. Mr. D. H. KENNEDY : Mr. Webb has given us some very interesting figures as to the average times taken by various traffic operations. Since reading his most admirable paper I thought it would be interesting to have, as some means of comparison, figures showing the minimum times which could be obtained when experiments were made under conditions which allowed of the operator doing the required operations in the minimum time and when she knew she was being tested. I took a large number of observations with a stop-watch, and I found it was possible, under the very best conditions and with the smartest operators, to complete the operation marked *A*, that is, the operation of observing the lamp and replying to the subscriber, in one second. I should like to say something about the slide showing the relay board.

A study of the conditions in the way I have described led to one or two interesting points. If you imagine that the operator is at the first position on the left you will see she has in front of her three panels. In this particular slide one of them is a blank panel, but at the Western Exchange, where these experiments were made, each of the three panels contained sixty lamps, and the operator was attending to a total of 178 subscribers. You will notice that in the panel on the left there is no pilot lamp. In the Post Office system a pilot lamp is provided for each panel. In the course of my experiment it was necessary to put out of use the pilot lamps. I found that this immediately caused a slowing of the operation—that whereas with the benefit of the three pilot lamps, which located the call into one of the three panels, the operator could do the operation in one second, without the pilot lamps it took a minimum of 1·9 seconds. Further, as is somewhat natural, the subscribers in the panel on the right hand could be dealt with more quickly than those in the middle or the left, speaking of a right-handed operator. In conducting these tests the psychological aspect of the question presented itself, namely, how quick was it possible for the human mind to act? It appeared that it was possible for four operations to be carried through in the short space of one second. In using the stop-watch method of timing I had to observe the lamp light at the same time as the operator; and as the operator was doubtless more accustomed to that operation her mind possibly worked quicker than mine. So I thought it would be possible to time the operation automatically, and after a little thought I arranged for a Wheatstone receiver to be joined in circuit to one panel. The centre panel, taking sixty subscribers, was connected to a Wheatstone circuit in such a way that, when a subscriber called, a current passed through the Wheatstone receiver, which immediately began to mark; then, by adjusting the receiver, so that the slip ran out at 1½ inches per second, it was possible to subsequently measure the length of the time during which the ink wheel had been down. In that way an accurate timing arrangement was secured, and it was easy to measure to tenths of a

Mr. Kennedy.

second. Subsequently, after dismissing the ideas of minimum times, I applied the arrangement to an ordinary operator who was unaware that she was being tested. This morning, during one hour, and taking a middle position, which, of course, only takes one-third of the calls, and without the operator being aware that she was under test, I obtained a record of thirty consecutive calls which were dealt with in a total elapsed time of fifty-nine seconds, giving an average of less than two seconds for the operation of replying to the subscribers. That emphasises the remarkable advantages which are due jointly to the use of the lamp as a signal and the close association of the lamp and the jack. I may say that I was able to institute a comparison, again referring to minima, between a board in the north of England, where we had the old system of jacks in one place and indicators in another. I remember making a large number of tests to find out what was the minimum time in which an operator could reply, and I was never able to get it below two seconds. So that, as Mr. Webb has stated, quicker operating has undoubtedly been obtained. It is interesting to know that his simile as to straight shooting was perhaps more apt than he realised, for in standing behind the operator I saw that if she did not get a bull's-eye on the jack right off it made two-fifths of a second difference. Then, again, endeavouring to get a minimum, I arranged for a number of junction calls to be got through with everybody on the *qui vive;* and we found it possible, after some few attempts, to get a junction call completed, that is, counting from the instant that the calling subscriber lifts the receiver through the linking up of the junction (requiring the co-operation of the two operators), to the instant that the called subscriber answers—he also being on the *qui vive*—that operation was actually completed in $7\frac{1}{5}$ seconds. You will perhaps realise more clearly what that means if I state that it involves altogether on the part of four individuals no less than sixteen mental operations all completed in $7\frac{1}{5}$ seconds. One concluding remark. Mr. Webb makes some illuminating comments on the history of telephonic development, and divides it into two periods, one of sixteen years, which is practically the magneto period, and another of eight years, which I think we may call the relay period. That division involves, I think, more than is shown in the paper. I think you might also say that it is a division between a period of sixteen years, in which English telephone engineers took a fair share in the development, and the later period of eight years in which development has been almost entirely due to the inventive genius of our good friends in America. There must be a reason for it. What is the reason that has led to us here to-night discussing figures which come from New York? In the matter of cable design English engineers have held their own; in the matter of the design of telephone apparatus they have fallen sadly into arrears. It is not because they were not there at the beginning of the problem. For over twenty years the Post Office has had a system which contained within it the germs of many of the attributes of the common battery system. It had, for instance, automatic calling, automatic clearing, and other attributes which we see

Mr. Kennedy.

nowadays arranged in a better form, due to the work which has been done in America. I think it is a very good thing for us to discuss what has been the cause of this, and the obvious reply, after every consideration, is the difference in the conditions. Telephonic development in America has taken place under the stress and strain of competition; here what development there has been, has taken place under a monopoly. We have, of course, benefited in that we have moved slowly, and we are moving along the best lines, but I think it is a right and pertinent thing for us to suggest to the telephonic powers of this country that it is perhaps not beyond the wit of man to devise some system which will introduce for all telephone people in England that inducement and incentive to invention which appears under competitive conditions in America.

Mr. Gill.

Mr. F. GILL: I understand this is the first paper we have had on telephone traffic at this Institution; it is a very complex subject, and all telephone men are very glad indeed to see a paper on it. The figures which the author has given are those of New York, and they show an exceedingly high standard of service. New York, as is well known, is the Mecca of telephone men. The service there is wonderfully good; their methods of handling it, their engineering, the way they take care of the service at present, the way they are proposing to take care of the service in the future and the development in the future are all models. And, lastly, those responsible for the methods are an exceptionally able body of men. Last year, when I was in the States, I stayed some time at New York, and I am very much pleased indeed to be able to make that statement from my own experience. There is one statement in the paper which I would like to correct. Mr. Webb says: "The use of lamp signals affords what was lacking before, a positive disconnection signal at the incoming end of the junction." I want to make one little point for this country, namely, that the positive disconnection signal at the incoming end of the junction was in use in this country, roughly in 1891 or 1892, I am not quite sure which, but it was a long time before lamp signals. It was a moderate use, I admit.

There is one point I should like to refer to which is not mentioned in the paper, and that is the connection between rates and traffic. I am not clear, but I fancy that in New York, under the magneto system, the flat rate was very largely used. The study of traffic has demonstrated quite clearly that the ordinary method of charge for telephone service by a flat rate, that is, where for a fixed rental an unlimited number of calls may be originated, is hopelessly wrong. When a subscriber takes a telephone, what he requires is the service; he does not want a line and the instrument at the end of it. The service is made up of a great many things. Every call that a subscriber sends has a very real effect; it is not a purely fictitious effect, as some people imagine, but there is a real effect on the size and complexity of the exchange apparatus, the junction plant, and the staff employed. We find that when a subscriber pays a fixed sum and can send as many messages as he likes, he undoubtedly sends many messages which are what one might call frivolous

—I do not want to quibble over the word, and I do not use it in any objectionable sense—but they are not serious messages, and those messages bring in an additional cost on the whole system. Therefore, the plant as a whole has by reason of these messages to be more costly than it ought to be. Mr. Webb has referred to the question of the bugbear of engaged or busy lines. In New York the number of cases in which "busy" is reported with regard to the subscribers' lines has fallen from 23 per cent. to 12½ per cent. That reduction is a good deal due to relay apparatus, and a good deal to the double supervision, but not all. To some very considerable extent it is due to the fact that people do not use the telephone unless they really want it, and to the fact that the measured rate encourages subscribers to have additional lines as required, rather than to allow their lines to be so occupied that it is a matter of difficulty to find them disengaged; in London we find that "engaged" is reported on 22 per cent. of the calls. Again, we find that the average calls per direct line in New York are 9 per day; in London they are 11·3 per day, that is to say, the London line is loaded roughly 25 per cent. more than the New York line. The plant has to carry that extra load, and to that extent it is a more expensive plant than it ought to be. If that were removed, obviously, as Mr. Gavey has pointed out, the capital costs of the exchange would be reduced, and with the capital costs that which is the real criterion and the only criterion, the annual costs. If that 25 per cent. were not imposed, the annual cost of working an exchange would be roughly 12 per cent. lower, and in addition there would be a very large reduction in the cost of the junction plant. It is no exaggeration to say that really sound engineering cannot be done in a large and busy area on the flat rate system. The cure for these evils is, of course, a measured service, by which the subscriber is charged for those messages which he sends. He gets a better service, he is only charged for what he sends, he does not send useless messages, and he does not pay for his office boy's messages. There is no more sense in charging a flat rate for telephone service than there is in charging a flat rate for the supply of electrical or any other energy. Mr. Gill.

I do not think sufficient stress has been laid upon the organisation that is necessary to deal with the traffic. If you put in the same equipment as they have at New York you will not get the same results, you must do something more; you require to pay constant and most careful attention to minute details. I do not know of any other department in ordinary life where one requires the same instant attention as one does on the telephone. If you go into a shop, or into a post-office, or a railway office you are content to wait your turn, but when you get on the telephone line you are very much more peremptory. I do not complain of that, because I think it operates to the good of the service, but it makes details very important. I should like to give some results which have been obtained in England on local calls. I do not for a moment put them up against the New York figures, because the conditions are entirely different; I simply give them for what they are worth. The first case is Nottingham, and I

Mr. Gill. have selected it because at Nottingham they have the particular type of board which Mr. Webb referred to. From O to A, that is from the call to the answer, took 4·4 seconds, a little longer than New York, which is 3·6 seconds. At Hull, with another relay equipment, it took 4 seconds. I have not got exactly the same steps as those given in the paper, so I will take a big step from O to D. At Nottingham it was 22 seconds against 30·39 seconds at New York. I do not attach any importance to that reduction; it is possible that the subscribers in Nottingham answer a little more quickly and probably there are fewer residences on the exchange. At Hull, from O to D took 20·5 seconds; then, as regards disconnection, at Nottingham it took 4·7 and at Hull 3·8 seconds. These are not isolated tests, they are the results of many tests and may be taken as reliable. Isolated tests taken here and there are not of the least use; you might as well leave them alone. If you want to do any good at testing service you must test continuously.

Figure B shows some other results as regards the speed of answer. The seconds which are observed between the time the subscriber calls and the time the operator replies to him, are plotted against the percentage of calls which are answered within the time. Curve A and curve C are for exactly the same exchange; it happened to be a magneto exchange. The average time for A was 7·4 seconds. Then we did a little organising; a new man was substituted, and he produced C with the same apparatus. C gives an average answer of 3·5 seconds; and you can see from the shape of the curve that it is not only very much better than A, but is also good in itself. B is taken on a standard relay equipment; that is also good. D is taken on another relay equipment; it is not quite what we call standard, but it is a relay equipment; it has double supervision and is a very fair type of board. The average time of D is 2·7 seconds; and you will see that 99 per cent. of the calls are answered in less than 5 seconds; while 76 per cent. of the calls are answered in less than 2½ seconds. All these curves are the results of a large number of tests.

The paper largely turns upon the use of common battery apparatus, and among the reasons why this type of apparatus has become so universal as practically to put out of account the construction of any other type of equipment, are that it enables one to simplify the subscriber's instrument and concentrate a highly specialised series of apparatus at the exchange where it can be properly looked after, and it permits the introduction of a large number of semi-automatic devices set in motion either by the operator or, unconsciously, by the subscriber. The co-operation on the part of the subscriber required by other systems is in fact too often absent, as illustrated by the author in the matter of speed of disconnection.

One sometimes hears the common battery system spoken about as if it were merely a particular kind of switchboard made by one manufacturer, and I have even seen it asserted that in the United States only the Bell Companies use it. The official census lately published by the U.S. Government shows that in December, 1902, there were in use by the Independent systems 481 common battery

exchanges against 356 such exchanges in use by the Bell Companies. Mr. Gill. No doubt those used by the Bell Companies embraced the larger systems, such as New York, Chicago, Boston, etc., but these figures clearly indicate that the Independent engineers also appreciate the advantages to be derived from relay equipment. In this country the

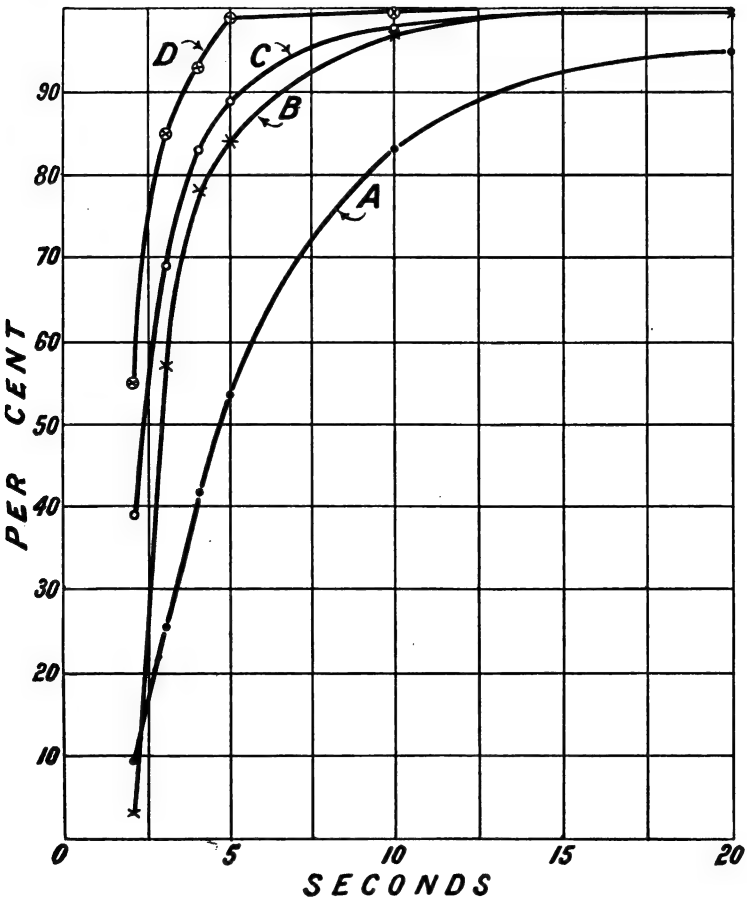


Fig. B.

National Telephone Company is following the same course; apart from the provinces it has now in hand a large conversion scheme in London. During the last twelve months common battery exchanges have been opened at Holborn, London Wall, North, and Sydenham; there are also in course of construction similar equipments for Hop, East, and Brixton, and there are others in various stages of preparatory work. The whole forms a scheme for complete relay working in

Mr. Gill. London, but of course until the alterations are further on one cannot hope for the full benefits of the change.

Mr. Preston. Mr. G. F. PRESTON (*communicated*): Every practical telephone man will be in agreement with the writer of the paper, on the importance of a close study of traffic, and there can be no question but that the remarkable results of which Mr. Webb gives particulars are the fruit of such study.

It is presumed that these observations were taken entirely unknown to the switchroom staffs, and if this were the case there can be no doubt that the service was of a highly satisfactory character at common battery exchanges. Presumably in the exchanges from whence these records were derived there was a great number of message or toll rate subscribers, and that the calls made by them were recorded by the depression of a meter key. If the meter key was depressed in handling such calls, at what period of the call did the depression take place?

It would, further, be of much interest to telephone men to learn something of the load that was placed upon an A or subscriber's operator that permitted such a service to be given, namely, what was the maximum number of calls that an A operator was called upon to handle during the busiest hour of the day, and perhaps in giving this figure the percentage of junction calls could be stated? Inasmuch as approximately 80 per cent. of the calls originated in the principal exchanges in New York and in London are junction calls, that is, have to be passed over a junction wire, it will be realised what an important part call or order wire working plays in telephone service.

It has long been understood that the New York authorities have paid great attention to this section of the work and endeavour to arrange the working of the order wire in such a manner that an A operator may have her demand instantly complied with, that is to say, the B operator is practically waiting to comply with the request of the A operator. Such being the case, what is the standard rate of call or order wire work in New York, *i.e.*, what is the number of demands passed over a call or order wire during the busiest hour of the day, and what number of junctions are generally controlled by one call wire between two busy exchanges? From these two figures it would be possible to determine the average number of calls passed over each junction wire during the busiest hour.

Another point in connection with junction working is, what number of call wires are placed at an A operator's disposal? Between two of the largest exchanges in New York there may exist eighty to one hundred junctions controlled by three or four call or order wires. Are the whole of these order wires repeated upon every A operator's position? In London at the present time, where we have three call wires working between two exchanges, it has been the practice to repeat each of these call-wires on all the A positions indicating those to be used by the operators by means of different coloured keys. It would be interesting to know whether this is the practice in New York. Do they permit an operator to try one call-wire after another if she is

Mr. Preston.

unable to obtain the allotment of a junction at the first or second effort, or is the work so arranged that rarely, if ever, she has to pass to a second or third call-wire? It is understood that in the States there is a piece of apparatus for automatically recording the time taken by an operator in answering calls. If Mr. Webb knows anything of such apparatus it would be of much interest if he could give particulars of same.

Mr. Cohen.

Mr. B. S. COHEN (*communicated*): Mr. Webb's paper has, I think, very conclusively shown the vast superiority of the common battery or relay system from the traffic dealing point of view. There are, however, two points in connection with this system with respect to which considerable misapprehension exists. The first is with regard to the relative transmission efficiencies for local and common battery working.

It has been stated that common battery talking is not so efficient as local battery talking. While it is true that local battery transmission can be made more efficient than common battery, this only holds good when the local cells are in quite new condition, at their maximum E.M.F. and minimum internal resistance, but unfortunately the primary cell has a pretty steep deterioration slope. It may be of interest to mention that, as a result of careful tests taken all over the country, an average practical condition for cells used for telephone purposes has been arrived at, and that comparisons of local and common battery systems have been carried out using these average condition cells. Under these conditions the transmission efficiency for a common battery circuit has been actually found to be about 17 per cent. better than the corresponding local battery circuit for lines of between 50 and 350 ohms resistance.

The second point which it may be of interest to mention is that extensions are quite as workable with common battery as with the old systems, although there seems to be an impression to the contrary. Common battery extension working is only just beginning to be extensively applied in this country, but I venture to think that the methods adopted will be found to embody sounder engineering principles and to give greater facilities than those used in connection with the older systems.

Mr. Webb mentions lamp flashing; it may perhaps be as well to state that in general practice there are only two flashing codes in use, one to flash the supervisory lamp in unison with the interrupted hum employed for engaged line signal and generally called the busy-back. The other is for flashing a supervisory signal to intimate to an operator that a subscriber she has connected has accepted a trunk call.

In connection with modern junction operating some of the factors not directly mentioned by Mr. Webb as increasing the efficiency may be pointed out. Firstly, the automatic ringing at the incoming or B end of the junctions. The junction operator merely depresses the button momentarily and the machine ringing key does the rest.

Then there is the guard signal. The junction operators' discon-

Mr. Cohen

necting lamp is arranged so as to light if the A or local operator takes the junction before the B operator, and this obviates error, as if the A operator makes a mistake, the B operator can locate it. Also in the later junction circuits the automatic ringing is not started until the A operator plugs in, and this prevents the subscriber at the B end being brought to the telephone unnecessarily in the event of the A operator plugging into the wrong jack.

Mr. Napier.

Mr. W. NAPIER (*communicated*): The subject selected by Mr. Webb is of the greatest possible interest to telephone engineers. It is only

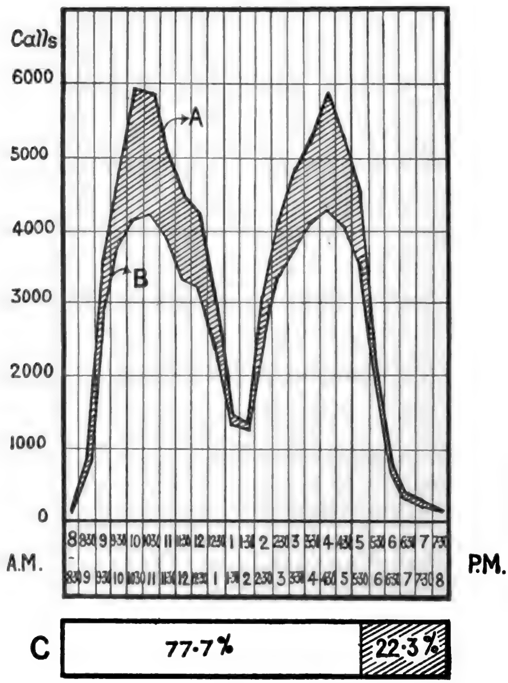


FIG. C.

by a careful study of the details of telephone working that the requirements of this great organisation can be ascertained and catered for. Important points which will have appealed to many are, first, absolutely reliable signals; secondly, effective supervisory signals which respond to the movements of both subscribers, and obviate the necessity for listening in on the part of the operator; thirdly, the simplest possible apparatus at the subscriber's end. Mr. Webb has touched very lightly on an essential point in the production of a good telephone service, viz., the absence of the reply, "Number engaged." This undoubtedly depends to a great extent upon reliable signals, the

Mr. Napier.

duration of connections, and the renting by subscribers of sufficient lines for their traffic. The question of rates, however, is one which must in the future receive fuller consideration. Taking the percentage of ineffective calls as twenty to twenty-three in a large exchange, it is readily seen that a large percentage of the costs for operating, apparatus, maintenance, etc., is involved, and that a reduction in this ineffective work will mean increased efficiency. The following observations were made in the Manchester Exchange.

The loss in one day due to engaged lines is shown in Fig. C, A being the total calls, effective and ineffective, and B the effective calls only. The shaded portion therefore represents the waste, amounting to 22·3 per cent. as shown on C.

Other tests proved that the percentage of engaged lines depends upon the rates and class of service to which the subscribers required contribute. The applications for flat rate subscribers averaged 22·9 per cent. ineffective per day, while applications for message rate subscribers only averaged 11·4 per cent. ineffective per day. Message rate subscribers pay per message and naturally control their traffic.

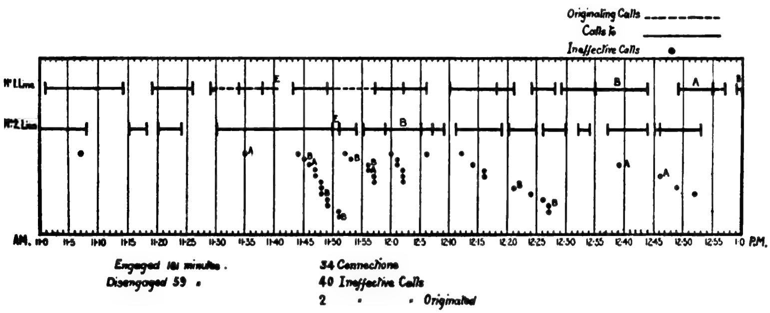


FIG. D.

Fig. D illustrates a case in which two exchange lines are rented by a subscriber and are totally inadequate to carry the traffic, the system being one in which subscribers ring through and can maintain a connection, although both parties leave their telephones. The diagram is divided off into minutes (120), so that with two lines there are 240 available minutes. The horizontal lines represent the durations of the connections, the continuous lines being connections to the subscriber in question, and the dotted lines the calls originated. Each single dot represents an ineffective call due to both lines being engaged. A and B represent repeated calls and connections confined to two callers, A and B; E calls originated by the subscriber for engaged lines.

The number of ineffective calls for these two lines between 11.45 a.m. and 12.30 p.m. is specially noticeable, and demonstrates the disadvantages of rates and systems which enable callers to have connections of length and frequency which debar other callers and

Mr. Napier. necessitate unproductive work. Up to the present this subscriber has not been induced to add to his lines, and the case is merely a sample of many in large exchanges. The relationship between traffic and rates is undoubted. There can be no doubt that traffic studies will pay the telephone engineer, and as millions of connections are involved the most minute detail is worth careful consideration.

Mr. Webb. Mr. WEBB (*in reply*): I think there is very little reply to be made. I am very glad that nobody has quarrelled seriously with the paper, or with any of the statements in it. I should like to say that I took the figures from New York for the purpose of making these comparisons, because it was the only large system that I was familiar with where there had been at one time uniform magneto equipment, and where there is to-day uniform relay equipment; it was not with any intention of parading the efficiency or smartness of New York, but simply on account of those conditions. I am very glad to have heard from Mr. Kennedy and Mr. Gill results that amply confirm the figures given in the paper. I think the discussion in general fulfils the object of the paper, which was to give an opportunity to telephone men for the discussion of this interesting subject. The paper is considerably compressed; in fact, I cut out of it altogether one subject to which Mr. Gill has made reference, because I did not think that one could cover the two subjects in an evening. My original idea was "Telephone Traffic and Telephone Tariffs," but I thought the title was too alliterative and the subject somewhat too long. But I thoroughly realise the very important relation between traffic and rates. I think most of the comments that have been made really result from the fact that the paper is very condensed, and that I have not elaborated many of the points that I do draw attention to. Mr. Cook chided me gently for not giving sufficient importance to the fact of the definite disconnection signal being obtained by the double supervision, but really unless I had used large capitals I do not think I could have said it more forcibly than I did when I stated that it constituted an immense advance in telephone operating.

(*Communicated.*) Referring again to Mr. Cook's remarks, I do not think it is mis-stating the case to say that automatic supervision has resulted from the use of lamp signals and central energy. It is possible to have automatic supervision without either lamp signals or central energy, but until lamp signals and central energy were in general use automatic supervision was not a part of telephone practice.

Both Mr. Kingsbury and Mr. Goddard say that the paper might have gone further in describing the lines on which traffic studies should be conducted. Undoubtedly it might; but if I had attempted to describe in detail what the paper refers to in essence there would have been no time for the interesting and valuable discussion which occurred. Mr. Kennedy's observations are of the greatest interest, and afford striking testimony of the truth of Mr. Gavey's remark, that modern telephone apparatus does more than make two blades grow where one grew before. With the telephone apparatus of the past era it would be impossible to achieve such results as those

Mr. Webb.

described by Mr. Kennedy; and it would be impossible, either with magneto apparatus or with the apparatus that is sometimes upheld in opposition to the common battery system, to work the system of 150,000 stations existing in New York to-day, and give even a reasonably efficient service to the public.

I entirely agree with Mr. Gill's remarks as to the close connection between traffic and rates, and as to the unsoundness of flat rates. In large cities there should be no flat rate, but the charges should be based exclusively on traffic—on the volume and range of the traffic originated by the individual user. The adoption of this principle is dictated not only by the fact that the amount of service used regulates both the cost of supply and the value received by the consumer, but also by the very important fact that the general efficiency of the service is higher under message rates than under flat rates—due, as Mr. Gill has pointed out, to the decrease of ineffective calls. I also thoroughly concur in Mr. Gill's observations as to the importance of organisation. Without the most thorough organisation the best apparatus is largely robbed of its value, while with efficient organisation surprisingly good results may be obtained from relatively inferior apparatus.

Not having all the data at hand, I cannot undertake to answer all Mr. Preston's questions. The service testing at New York is entirely secret to the operating staff. The service is almost exclusively message rate, and in any case, for statistical purposes, the meter keys are used on all connections. The meter key is pressed just before the operator takes the connection down. I regret that I have not complete information available on the other points raised; these deal with details in which it is important to be accurate, and are dependent on local conditions subject to more or less continuous variation. It would perhaps be safer for Mr. Preston to apply directly to the New York Telephone Company for the information he seeks.

As Mr. Cohen has pointed out, it is occasionally alleged by those who adopt an uncompromising attitude toward common battery working that the talking by common battery is inferior to local battery talking. Mr. Cohen is quite correct in saying that under the best conditions local battery talking is better than the average common battery talking; but it is unquestionable that the average common battery talking is superior to the average local battery talking.

Mr. Napier draws attention to a highly interesting point—the unwillingness of the British telephone subscriber to use his telephone service properly or to use and pay for sufficient telephone facilities to cope with his traffic. The education of the telephone subscriber has been greatly neglected in this country, and the education of the user is an important item in traffic study, and indeed in telephone management generally.

The President.

The PRESIDENT: I now ask you to give a formal vote of thanks to the author for the very interesting paper he has brought before us.

The resolution was carried by acclamation.

The Four Hundred and Twenty-eighth Ordinary General Meeting of the Institution was held in the Rooms of the Society of Arts, John Street, Adelphi, on Thursday evening, May 25, 1905—Mr. ALEXANDER SIEMENS, President, in the chair.

The minutes of the Ordinary General Meeting held on May 11, 1905, were taken as read and confirmed.

The list of candidates for election into the Institution was taken as read, and it was ordered that it should be suspended in the Library.

The following list of transfers was published as having been approved by the Council :—

TRANSFERS.

From the class of Associate Members to that of Members—

Sidney G. Brown.	Richard J. Hughes.

From the class of Associates to that of Associate Members—

Frederick W. Carter.	Ernest W. L. Harrison.
William C. Grinyer.	James A Sykes.

Henry T. Van Straubenzee.

Messrs. P. M. Hampshire and H. G. Wood were appointed scrutineers of the ballot for the election of new members, and at the end of the meeting the following were declared to have been duly elected :—

ELECTIONS.

Associate Member.

George Percival Cooper.

Students.

Herbert Dieudonné Gervers.	Ratcliffe Wright.

Donations to the *Library* were announced as having been received since the last meeting from Professor A. Jamieson (through Messrs. Griffin & Co.); and to the *Building Fund* from Messrs. J. R. Bedford and E. Hutchinson, to whom the thanks of the meeting were duly accorded.

The following paper was read and discussed, and the meeting adjourned at 9.40 p.m.

WIRELESS TELEGRAPHY MEASUREMENTS.

By W. DUDDELL, Member, and J. E. TAYLOR, Associate Member.

(*Paper read May* 25, 1905.)

In spite of the very large amount of matter that has been published on the subject of wireless telegraphy, there are very few quantitative data available. The object of the present tests was to measure the R.M.S. value of the current in the receiving air wire and to determine as far as possible how this current depends on the arrangement of the transmitting and receiving apparatus and the distance between them. Object of tests.

The following preliminary tests were officially carried out by the authors for the Postal Telegraph Department, at the instance and under the control of the Engineer-in-Chief, Mr. J. Gavey, C.B., in Bushy Park, in June, 1904.

The tests were made between a transmitting station which could be easily and quickly moved to any part of Bushy Park as required, and a receiving station which was set up in a fixed position for about one-half of the tests, and was then taken down and re-set up in a fresh position and many of the former tests repeated. Apparatus used.

All the transmitting apparatus was fitted up inside a large Post Office temporary telegraph-van, behind the driver's seat of which a bamboo mast was fixed. The vertical wire, a 7/22 G.P. (cable core), was suspended from a spar on this mast, and could be raised or lowered as required. The earth connection was made to the centre of a piece of galvanised iron wire netting 76 ft. long and 3 ft. 10 in. wide, fixed flat on the top of the grass alongside of the van. The movable transmitter.

In all the experiments given in this paper, the vertical wire was directly connected to the closed oscillating circuit, as shown in the diagram of connections (Fig. 1). The method of operation is based on the excitation of oscillations in the antenna by directly connecting it to a closed oscillating circuit, some other point of which is connected to earth. There are thus two distinct resonant systems, one a closed circuit consisting of a condenser and inductance spiral L, and the other the antenna, inductance spirals H and L, and the wire netting or surface of the ground. When made to have the same period of electric vibration, oscillations are communicated to the antenna. Adjustment for this purpose was made by altering the self-induction H until the current in the air wire was a maximum as indicated on the thermal ammeter A. A well-defined maximum was readily obtained in this

way, though sharper tuning could have been reached by reducing the amount of coupling between the two resonant systems. It was found, under the conditions of working, that there corresponded to each combination of self-induction and capacity a spark length which gave the required current in the transmitter air wire. The frequency of the oscillations was altered when required by changing the size and number of the jars used, and the vertical wire was always tuned to suit the oscillating circuit by altering the number of the turns of the self-induction H in series with it. This adjustment was made by observing the current by the Duddell Thermo-ammeter A and adjusting

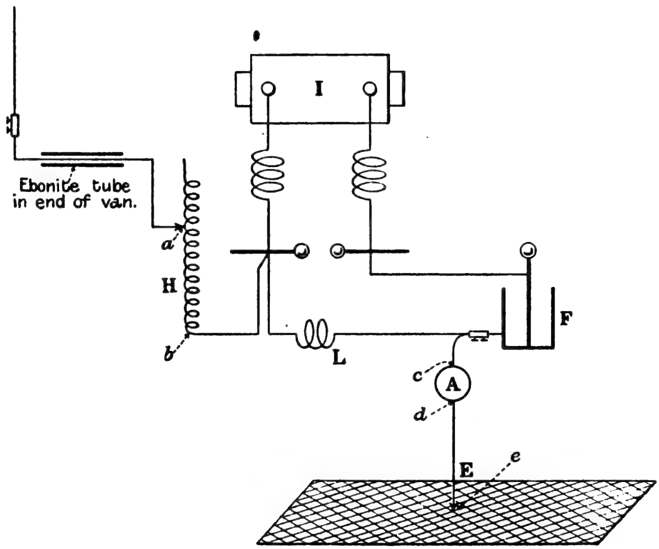


FIG. 1.

the number of the turns of the self-induction till this current was a maximum. The self-induction H consisted of 71 turns made by winding two No. 16 tinned copper wires side by side, touching one another in a shallow screw thread on a wooden cylinder 4 in. diameter and 18 in. long. The jar or jars F were charged by an induction coil I through two choking coils, intended to protect the induction coil from the oscillatory currents. The induction coil (a 30 cm. spark size instrument) was supplied by 15 accumulators, a resistance being used in series with the coil. Two different interrupters were used : (1) A Mercury Turbine Interrupter ; (2) A Grisson Interrupter.*

* The Grisson Interrupter is used with a special induction coil or transformer having a connection made to the middle point of the primary so that a current flowing in at this point and dividing equally between the two halves produces no magnetic field. This point is connected to one pole of the battery, the other two

The Mercury Turbine Interrupter was driven in all the tests at a speed of 1,070 revolutions per minute giving 17·9 trains of oscillations per second; and the latter was run at 1,500 revolutions per minute giving about 100 trains of oscillations per second.

Signals lasting thirty seconds with an equal time interval between them were regularly sent from the transmitter, and during each signal an observation of the current in the vertical receiving wire was made. In general from 8 to 12 such observations were taken for each experiment.

In most of the tests the height of the top of the vertical transmitting wire from the ground was 42 ft., the length of wire from the top to the terminal of the self-induction being 48 ft. 6 in. The length of the earth connection was 28 ft. 4 in., and about 4 ft. 6 in. of wire was used in making the connections between the self-induction, spark-gap, jars, and ammeter inside the van.

Three different wave lengths were used in the tests, obtained by altering the capacity in the oscillating circuit, and tuning the vertical wire to suit. In each case the self-induction L in the oscillating circuit, which consisted of two turns of stranded conductor wound on a wood core 127 mm. diameter, 7 mm. pitch, was kept the same. The stranded conductor consisted of nineteen No. 22 copper wires, each separately silk covered. Wave lengths used.

Wave No. 1.—The capacity F consisted of one 4-pint jar half-covered with tinfoil. Wave length about 375 ft.* With this wave length and the vertical wire 42 ft. high, the following data were always worked to unless stated to the contrary:—

Spark length 5·29 mm.
Current in vertical wire about 0·36 ampere with Mercury Interrupter.
Number of turns of self-induction in series with vertical wire, 12.

Wave No. 2.—The capacity F consisted of one 4-pint jar completely covered with tinfoil. Wave length about 400 ft. With 42 ft. vertical wire, unless stated to the contrary, the other data are:—

Spark length 7·08 mm.
Current in vertical wire about 0·50 ampere with Mercury Interrupter.
Number of turns of self-induction in series with vertical wire, 18.

terminals being connected alternately with the other pole of the battery by means of a revolving commutator. The following series of actions takes place:—

1. Current through first half of primary, magnetising core.
2. „ „ both halves, no magnetisation.
3. „ „ second half of primary, core oppositely magnetised.
4. „ „ both halves, no magnetisation.

In action it is necessary to regulate the speed of the commutator so as to produce a resonance between the secondary circuit and the rate of reversal in the primary.

* For basis on which these wave lengths were computed, see p. 341.

Wave No. 3.—The capacity F consisted of two 4-pint jars completely covered with tinfoil used in parallel.

Wave length about 500 ft.

With 42 ft. vertical wire, unless stated to the contrary, the other data are :—

Spark length 4·55 mm.
Current in vertical wire about 0·50 ampere with Mercury Interrupter.
Current in vertical wire about 0·70 ampere with Grisson Interrupter.

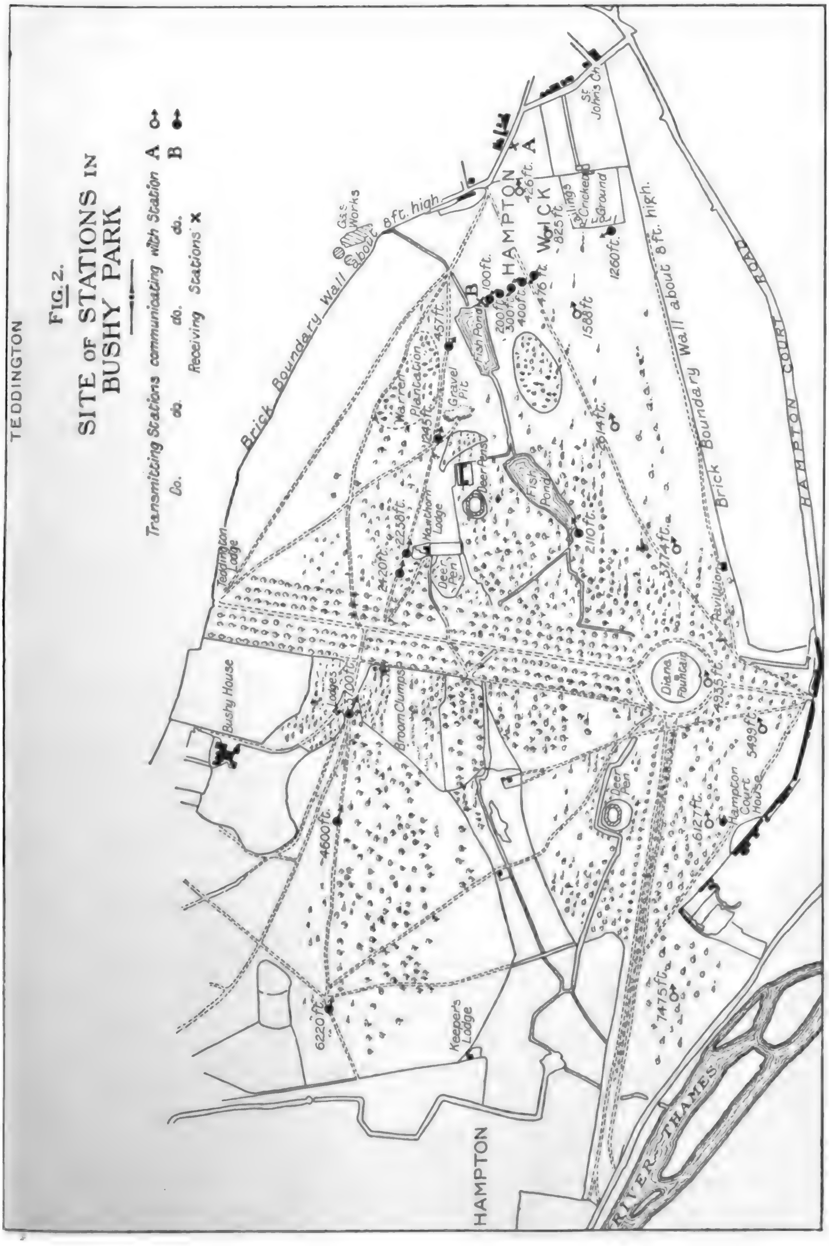
Number of turns of self-induction in series with vertical wire, 40.

The receiver.

The receiver was first set up in a paddock at the point marked A on the accompanying map (Fig. 2). The vertical wire was suspended from a spar fixed to the top of a terminal pole belonging to the telephone system ; the overhead telephone wires ended at this pole and were taken down the side of the pole and under the park in a cable. The terminal pole was stayed with stout, stranded iron wire. To make certain what effect these telephone wires and stays were having on the results the receiver was moved to point B on the map (Fig. 2), near the fish-ponds. In this position the vertical wire was hung from a light bamboo tied to the top of a L.C.C. fire-escape. The receiving instruments were, in each case, set up inside a small wooden contractor's office. The vertical air wire, a 7/22 G.P. (cable core), was connected to a variable self-induction the same size as that used in the transmitter circuit (H, Fig. 1), and the other end of this self-induction was connected to earth through a Duddell thermogalvanometer,* which was used to measure the received current. The earth connection was made to the centre of a piece of wire netting 77 ft. long by 3 ft. 10 ins. wide. The vertical height of the air wire from the ground was in most of the tests 56 ft., the total length of wire from the top to the terminal of the self-induction being 65 ft. and the length of the earth connection 19 ft. 3 ins. The receiving circuit was tuned by altering the number of turns in the self-induction until the current as shown by the thermogalvanometer was a maximum. Observations were generally made both with the circuit tuned as above and also with the air wire connected direct to earth through the thermogalvanometer without any self-induction in series; this arrangement will be called "untuned."

In the thermogalvanometer the current to be measured flows through a fine resistance about 3 mm. long, and the heat given out by it falls on a small thermo-junction fixed to the moving part of the instrument. The sensibility can be altered either by varying the resistance of the heater, or by altering the distance between the heater and the thermo-junction. The resistance of the heaters used was about 100 ohms, and the sensibility was adjusted by changing the

* *Philosophical Magazine*, July, 1904.



Reproduced from the Ordnance Survey Map with the sanction of the Controller of H.M. Stationery Office.

distance between the heater and the thermo-junction, so that, throughout each series of tests, both the resistance and the lengths of wire used in the measuring circuit remained constant.

Height of Transmitting Air Wire Varied.

Results. Three different lengths of wire were used so as to make the vertical height of the transmitting air wire 21, 31·5 and 42 ft. The arrangement of the closed oscillating circuit, and consequently its own frequency of oscillation, was not altered: the air wire being re-tuned to the same frequency as the oscillating circuit by altering the number of turns of the self-induction in series with it. When the height of the air wire is increased, we may keep the power supplied to the coil and the length of the spark-gap constant, in which case the current in the air wire will also increase, though not in the same proportion; or we can keep this current constant by altering the spark-gap and the power supplied to the coil. Both these arrangements were tested. The results are given in Table I. The tests were repeated with two different wave lengths. Of course during the tests the arrangements at the receiver end were kept constant.

Taking first the figures for the receiver tuned to the same frequency as the transmitter, and the current in the transmitter air wire kept approximately constant, it is seen that the received current is very closely proportioned to the height of the transmitter air wire. In the results, where both the height and the current in the transmitter air wire varied (spark length constant), the received current is nearly proportional to the product of the height into the current in the transmitter. So that calling the vertical height of the transmitter air wire h and the current flowing into it A, we may write the received current, in micro-amperes, khA, where k is a constant which has the value 16·6 for Wave No. 1 and 20 for Wave No. 2, h being in feet and A in amperes. Using these two constants, a column of calculated currents has been worked out for comparison with the observed values.

Turning next to the results with the plain air wire receiver (untuned), it is not possible to find values for the constant k which will fit the results at all satisfactorily. The nearest values are $k = 5·3$ for Wave No. 3, and 16·7 for Wave No. 1.

These observations require to be extended on a larger scale before it can be said what the exact relation is between the height of the transmitting antenna and the current in the receiving air wire, though it appears to tend towards a simple ratio.

The effect of varying the height of the receiver air wire is considered on p. 330.

Arrangement of Transmitter Air Wire Varied.

The results obtained are given in Table II. The main point to be noted is, that taking a constant length of transmitter air wire and reducing its vertical height to one half, by rolling up half of it at the top, or by carrying it out horizontally for half its length and then

TABLE I.

Height of Transmitting Air Wire Varied.

Receiver in Paddock, distance 1,588 ft.
Height of Receiver Air Wire, 56 ft.
Mercury Interrupter.

Vertical Height of Transmitter Air Wire.	Turns of Self-Induction in Series with Transmitter Air Wire.	Spark-gap Length.	Current in Transmitting Air Wire.	Receiver.			
				Tuned.		Air Wire only.	
				Current Observed.	Calculated Current if $k = 16{\cdot}6$.	Current Observed.	Calculated Current if $k = 5{\cdot}3$.
Feet.	—	Millimetres.	Amperes.	Micro-amperes.	Micro-amperes.	Micro-amperes.	Micro-amperes.
Wave No. 3 (500 ft.).							
21	66	5·21	0·351	121	122	38·5	39·1
31·5	52	3·86	0·355	188·5	185·5	60	59·3
42	40	3·48	0·352	246	246	81·5	78·5
21	66	3·48	0·286	100	99·5	30·5	31·8
31·5	52	3·48	0·334	174·5	174·5	55	55·7
42	43	3·48	0·359	250·5	250	82·5	79·9
Wave No. 1 (375 ft.).							
—	—	—	—	—	$k = 20$	—	$k = 16{\cdot}7$
21	26	10·04	0·352	140	147·5	109	123
31·5	18	8·26	0·351	223	221·5	183	185
42	12	6·35	0·360	315	302·5	272·5	252
21	26	5·39	0·305	126	128	103	107
31·5	18	5·39	0·339	213	213·5	182	178
42	12	5·39	0·355	308	298	270·5	248·5

TABLE II.

Arrangement of Transmitter Air Wire Varied.

Receiver in Paddock, distance 1,588 ft.
Height of Receiver Air Wire, 56 ft.
Spark-gap, 4·55 mm.
Mercury Interrupter. Wave No. 3 (500 ft.).

Arrangement of Transmitter Air Wire.	Current in Transmitter Air Wire. Amperes.	Current in Receiver.	
		Tuned. Micro-amperes.	Air Wire only. Micro-amperes.
Straight Transmitter Air Wire; vertical height from ground, 42 ft.	0·484	315	106
Shaped Air Wire, same total length; vertical height, 31·5 ft.	0·485	208	69
Same vertical height, 21 ft. ...	0·473	159	51
Shaped Air Wire; vertical height of horizontal part, 22 ft.; length of horizontal part, 20 ft. Horizontal part pointing towards receiving station and on same side of van as netting.	0·50	238	73
Same, but horizontal part on opposite side of van to netting.	0·466	224	72
Same, but horizontal part at right angles to line of transmission.	0·457	229	73
Half Air Wire rolled up at top; vertical height, 21 ft.	0·441	158	48
Loop Air Wire; vertical height, 22 ft.	0·455	148	47

fixing the remainder vertical, or by forming a vertical loop, the current in the receiving air wire is reduced to approximately one half the value it has for the whole transmitter wire vertical. So that reducing the vertical height by any of these methods has the same effect as cutting off the wire from the top as found in last section. Taking the air wire having a vertical height of 21 ft., we have found that if an additional 21 ft. be added to the top so as to make the vertical height 42 ft. the received current is doubled; if, however, the extra 21 ft. be added horizontally to the top, so as not to increase the vertical height, the received current is still increased by 50 per cent. Thus an air

wire 21 ft. high with 20 ft. of wire connected to it in a horizontal position at the top produced more current in the receiver than an air wire 31 ft. 6 in. high.

Earth Connections Varied.

In all the tests given in this report, except those detailed in this section, the earth connection at each station consisted of about 76 ft. of wire netting flat on the grass. The tests given in Table III. show

TABLE III.

Earth Connections Varied.

Receiver in Paddock, distance 428 ft.
Height of Receiver Air Wire, 56 ft.
Height of Transmitter Air Wire, 42 ft.
Spark-gap, 4·55 mm.
Grisson Interrupter. Wave No. 3 (500 ft.).

	Current in Transmitter Air Wire.	Current in Receiver Air Wire. Tuned.
	Amperes.	Micro-amps.
Receiver Earth altered.		
(Transmitter netting all flat on earth.)		
Wire netting earth; 77 ft. of netting flat on earth	0·696	2,042
Earthed to lead sheathing of cable	0·696	1,246
Earthed to stay on terminal pole	0·696	1,346
¼ of wire netting rolled up from one end ...	0·698	1,968
¼ of netting „ „ each end ...	0·696	2,016
½ of netting „ „ one end ...	0·702	1,797
½ of netting „ „ each end, *i.e.*, all rolled up but resting on the earth	0·696	1,530
½ of netting rolled up from one end and ¼ of netting rolled up from the other	0·700	2,026
Transmitter Earth altered.		
(Receiver netting all flat on earth.)		
½ of netting rolled up from one end... ...	0·611	2,031
½ of netting rolled up from each end, *i.e.*, all rolled up but resting on the earth... ...	0·392	1,129

that only the centre part of the netting near where the earth wire was fixed to it, was effective; the two extreme ends of the netting appear to make no appreciable effect on the result. This seems to indicate that it would be better to use a circular piece of netting for the earth with the wire connected to the centre, rather than a long strip, as was used in these experiments.

An attempt was made to obtain a better earth by connecting the earth wire to the lead sheathing of the telephone cable, which is under the park, but the received current with this connection was only about 60 per cent. of that obtained with the netting earth. This telephone cable is armoured and laid direct in the earth. An earth was also made on the iron stay of the terminal pole, and a slightly better result obtained than with the connection to the lead sheath of the cable. The question of the earth connection for wireless telegraphy is a most important one, and requires very thorough investigation.

It was several times noticed that the current into the transmitter air wire was slightly diminished at the commencement of a shower of rain. Thus, after the weather had been dry for about a week, a heavy rainstorm reduced the current by about 2 per cent. This appeared to be due to altering the conditions of the earth rather than to any effect on the air wire. Re-tuning did not reproduce the original current.

Height of Receiving Air Wire Varied.

The transmitting conditions were kept constant and the height of the receiving air wire was varied by using vertical wires of different lengths. The receiving circuit was re-tuned to suit each height of vertical wire by altering the self-induction in series with it. Observations of the received current were made both with the air wire tuned as above and untuned, that is with no self-induction in series with it. The results are given in Curve I.

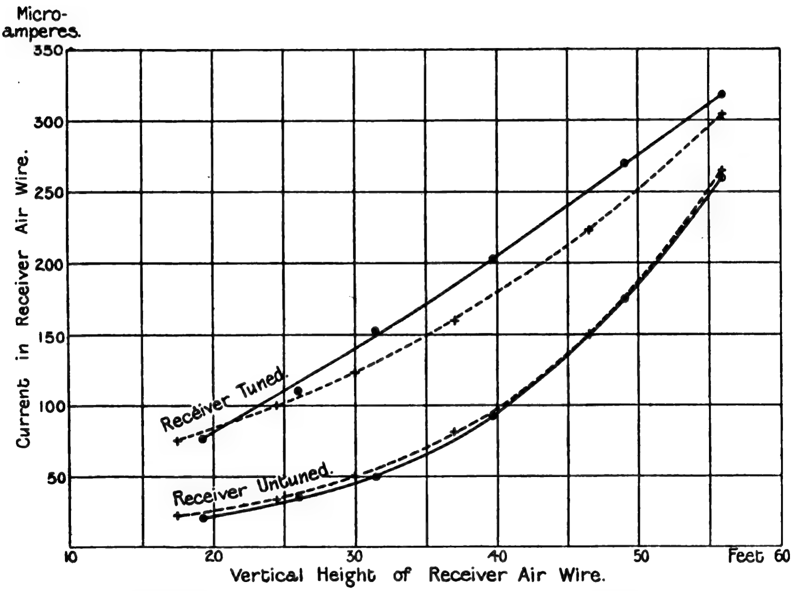
Taking the tuned results first and the receiver near the fish-ponds, where the screening of the receiver was comparatively small, the law connecting the height of the receiver air wire and the current in it, is practically linear between 30 and 56 ft.; below 30 ft. the current increases less rapidly than the height. With the receiver in the paddock and the air wire suspended from a spar fixed to the top of a terminal pole so that the lower part of the air wire was screened by the stays and other conductors, the curve between height and current does not become linear even at the top.

That there was considerable loss of energy when the receiver was in the paddock is shown by the fact that rather more current was observed when the receiver was near the fish-ponds and the transmitter at a distance of 2,110 ft. than when the receiver was in the paddock and the transmitter 1,588 ft. away; or, in other words, equally strong signals were received at one-third greater distance when the receiver was not in the paddock.

It will be observed that the curve of tuned received current in the more screened situation (the paddock) more nearly approaches the shape of the untuned current curves, owing, probably, to the

damping losses in the wires, stays, etc., on the pole. This point is not without practical significance, inasmuch as it would indicate that to obtain the sharpest tuning the stay wires of wireless telegraphy masts should be well divided up into short insulated sections to avoid the production of oscillations in them which would cause damping in the receiver.

Without the self-induction in the air wire, increasing the height naturally increases the received current very rapidly, under the conditions of the experiment, as it not only increases the E.M.F. induced in the wire, but also improves the tuning, so that a larger current is obtained even for the same induced E.M.F.



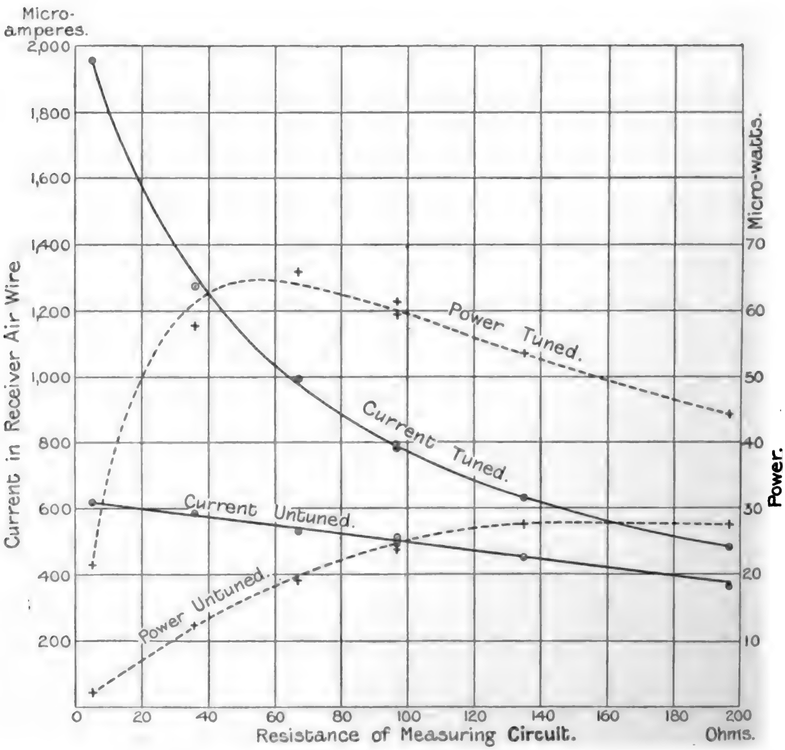
CURVES I.—Height of Receiver Air Wire varied. Full lines Receiver near Fish Ponds. Dotted lines Receiver in Paddock.

The tests were commenced in rainy weather, but nearly the whole of the results given were obtained in dry weather. No considerable effect on the strength of the received signals was noticed when it changed from wet to fine.

RESISTANCE OF MEASURING INSTRUMENT VARIED.

In order to investigate the effect that the resistance of the measuring instrument in series with the receiver air wire had on the value of the received current, a low resistance (5·55 ohms.) heater was placed in the thermogalvanometer and additional resistances were used in series with it, so as to increase the resistance as required. Each of these resistances consisted of a single $\wedge$ loop of (0·001″) Kruppin wire,

the total length of wire in the longest one, which had 99 ohms resistance, being only 7 cm. Not more than three of these resistances were ever used in series with the instrument at one time, so that the self-induction and capacity effect of these resistances was probably small. The total resistance, that is the resistance to steady currents, of the thermogalvanometer and above series resistance is given in column 1 of Table IV., and the observed current in column 2. From the observed current and resistance the available power in the measur-



CURVES II.—Resistance of Measuring Instrument varied.

ing circuit has been calculated as C^2R. These values, both for the receiving circuit, tuned and untuned, are plotted in Curves II. In the tuned condition, the available power reached a maximum when the receiving circuit had a resistance of about 60 ohms, so that it is evident that this would be the correct resistance to give to any receiver of the thermal type used directly in series with this air wire. The current decreases very rapidly with increase of resistance and almost exactly according to the relation : Current (tuned) $= \dfrac{0.12}{(56 + r)}$ when r is the total resistance of the measuring circuit. With the

receiver air wire only, the results may be expressed: Current (untuned $= \frac{0\cdot12}{\sqrt{(185)^2 + (56+r)^2}}$. The values of the current calculated from the above formulæ are given in Table IV. for comparison with

TABLE IV.

Resistance of Measuring Instrument Varied.

Receiver near fish-ponds, distance 1,245 ft.
Height of Receiver Air Wire, 56 ft.
Height of Transmitter Air Wire, 42 ft.
Current in Transmitter Air Wire, 0·486 ampere.
Spark-gap, 7·08 mm.
Mercury Interrupter. Wave No. 2 (400 ft.).

Total Resistance. Ohms.	Tuned.			Air Wire only.		
	Current. Micro-amperes.	C^2 R. Micro-watts.	Calculated Current. Micro-amperes.	Current. Micro-amperes.	C^2 R. Micro-watts.	Calculated Current. Micro-amperes.
5·55	1,958	21·3	1,950	616	2·11	616
35·9	1,269	57·9	1,306	583	12·2	581·5
66·6	995	65·9	979	537	19·2	541
97·0	795	61·3	784	507	24·9	500
97·0	784	59·6	784	498	24·1	500
135·1	628	53·3	628	454	27·8	451·5
196·2	475	44·3	476	372	27·2	383·5

the observed values. The agreement between them is very close. Taking the formula $\frac{0.12}{\sqrt{(185)^2 + (56+r)^2}}$ the first point to be noted is that it is of the same form as the equation giving the current in an ordinary alternating current circuit, containing resistance, self-induction and capacity in series. If in such a circuit the self-induction be adjusted so as to give a resonance $(Lp - \frac{1}{Fp} = O)$ *i.e.*, the circuit be tuned to the same period as the impressed E.M.F., then the first term $(185)^2$ will vanish, and we get our "tuned" equation as we find by experiment. To get a good resonance or sharp tuning in such a circuit it is also necessary that the term $(56+r)^2$ should be as small as possible. Therefore to get the best tuning r should be

small, but to obtain the most energy to work the receiving instrument r should be about 56 ohms. If, however, the constant 56 can be reduced, both the sharpness of the tuning and the available power may be proportionately increased. It is, therefore, of great importance to inquire what causes the vertical receiving air wire to dissipate energy as if it had a resistance of 56 ohms. Part, at least, of this effect is no doubt due to radiation, but some part may be due to losses at the earth connection and to eddy current losses in the oscillating system. It should be observed that when a dissipation factor of this magnitude is associated with the air wire system it becomes important, if tuning is to be kept sharp in order to obtain the greatest "selectiveness" in wireless telegraphy, to attain the selectiveness by the use of associated resonant circuits in which the damping losses are made very much smaller.

Returning to the equation for the current, it is seen that the current flows as if an E.M.F. of 0·12 volt is induced in the air wire. Now this is a root mean square voltage, the mean not being taken over the time each set of oscillations continues, but over the time each set lasts, *plus* the time between it and the next set.

It is improbable that the groups or sets of effective oscillations last much more than $\frac{1}{3000}$th of the time interval between them,* so that the R.M.S. voltage induced during the oscillations cannot be much less than $0{\cdot}12 \times \sqrt{3000} = 6{\cdot}6$ volts under the conditions of very strong signals used for these tests.

Voltage Produced at Coherer Terminals.

Though no precise measurements bearing on the point were made, it may be taken in view of the manner in which the coherer receiver used at intervals during the experiments responded at the longer distances, that the E.M.F. of 6·6 volts given in the previous paragraph was about eight times stronger than necessary to get signals on that particular coherer. The critical R.M.S. electromotive force during each train in the receiver antenna required to operate the coherer, would therefore be about $\frac{6{\cdot}6}{8} = 0{\cdot}8$ volt. This was not the actual voltage applied to the coherer terminals, however, because the coherer was always connected in a secondary circuit tuned to resonance in which it may be taken that the E.M.F. was magnified perhaps ten times, giving 8·0 volts per train (R.M.S.) In this secondary resonant circuit a special form of construction has been adopted and every precaution taken to reduce the damping to a minimum. To get an idea of the maximum voltage attained during a train of oscillations in this circuit, it is necessary to take into consideration the increment and decrement of the train. Allowing for this, it is thought safe to assume that an actual maximum E.M.F. of about four or five times the R.M.S. figure, viz., about 40 volts, should be available in the coherent resonant circuit to give good signals. As in practical work it would be necessary to provide a con-

* Taken on a basis of fifty effective cycles per train.

siderable margin above this figure, it is clear that the maximum voltages produced are not of a very small order.

Energy of Oscillations in Radiating System of Transmitter.

Seeing that it is necessary, in the case of the receiving oscillatory system, to assume a dissipation factor of 56 ohms, it is highly probable that a similar but somewhat larger dissipation factor is involved in the case of the transmitter radiating system. The radiation coefficient should be approximately the same in each case, the systems being similar, but there can be little doubt that dielectric losses and brush discharges due to the high tension at the transmitter would increase

TABLE V.

Distance between Transmitter and Receiver Varied.

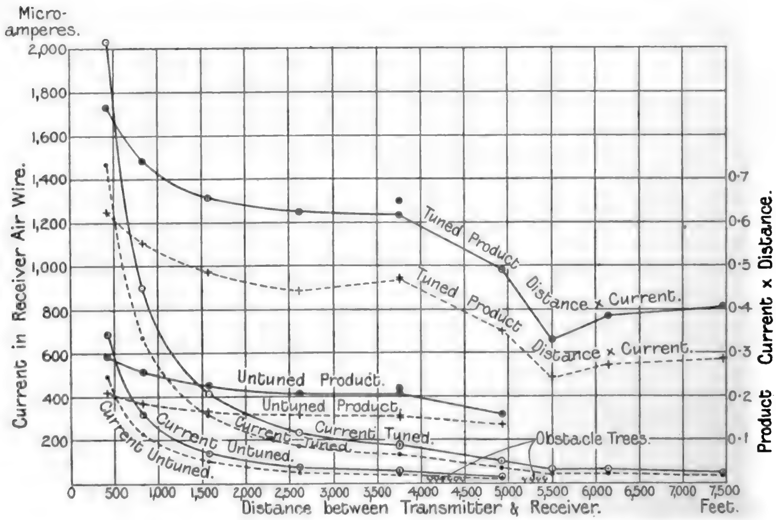
Receiver in Paddock.
Height of Receiver Air Wire, 56 ft.
Height of Transmitter Air Wire, 42 ft.
Current in Transmitter Air Wire: Mercury Interrupter, 0·499 ampere; Grisson Interrupter, 0·690 ampere.
Spark-gap, 4·55 mm. Wave No. 3 (500 ft.).

Distance between Transmitter and Receiver in Feet.	Mercury Interrupter.				Grisson Interrupter.			
	Tuned.		Air Wire Only.		Tuned.		Air Wire Only.	
	Current in Receiver Air Wire in Micro-amperes.	Product, Current × Distance.	Current in Receiver Air Wire in Micro-amperes.	Product, Current × Distance.	Current in Receiver Air Wire in Micro-amperes.	Product, Current × Distance.	Current in Receiver Air Wire in Micro-amperes.	Product, Current × Distance.
428	1,466	0·628	489	0·2093	2,028	0·868	686	0·2935
825	668	0·551	226	0·1864	898	0·741	310	0·2557
1,588	305	0·485	101·5	0·1613	412	0·654	141	0·2240
2,614	169	0·442	58·6	0·153	238	0·623	77·6	0·2028
3,774	123·3	0·466	40	0·151	164	0·619	54	0·204
3,774	124·2	0·469	40·7	0·154	172	0·650	56·5	0·213
4,935	71	0·351	27	0·133	99·5	0·491	32	0·158
5,499	44	0·242	—	—	61·6	0·339	—	—
6,127	44·3	0·271	—	—	62·5	0·383	—	—
7,475	38·3	0·286	—	—	54	0·403	—	—

the dissipation to some extent. For the purpose of calculating the energy of the transmitter oscillations, the dissipation factor is therefore assumed, at a venture, to be 60 ohms, and the following figures are obtained for the different waves used in the experiments :—

	R.M.S. Current.		C^2R Watts.
Wave No. 1. Mercury Interrupter	0·36	...	7·8
„ „ 2. „ „	0·486	...	14·2
„ „ 3. „ „	0·5	...	15·0

The greatest proportion of this energy picked up by the receiver was about $\frac{1}{600}$th part at a distance of 100 ft., and the smallest proportion somewhat less than one six-millionth part at a distance of 7,475 ft.



CURVES III.—Distance between Transmitter and Receiver varied. Full lines Grisson Interrupter. Dotted lines Mercury Interrupter. Receiver in Paddock, Position A on Map.

For the different waves the power used in the whole primary circuit of the transmitting apparatus varied between 100 and 200 watts roughly, so that only a small percentage of the applied energy was converted into useful oscillations in the radiating system.

DISTANCE BETWEEN TRANSMITTER AND RECEIVER VARIED.

All the conditions at both the transmitting and receiving stations were kept as far as possible constant, and the distance between the two stations was altered by moving the transmitter. The successive positions of the transmitter are indicated on the map (Fig. 2). It was found impossible to get exactly the same current in the transmitter air wire at the different positions of the transmitter, keeping the spark length fixed. With the Mercury Interrupter the current varied ± 1 per cent. from the mean, and with the Grisson Interrupter ± 1¾ per cent. in the

first set of experiments (Table V. and Curve III.) In the second and third sets of experiments (Table VI. and Curves IV. and V.), the variations were much greater.

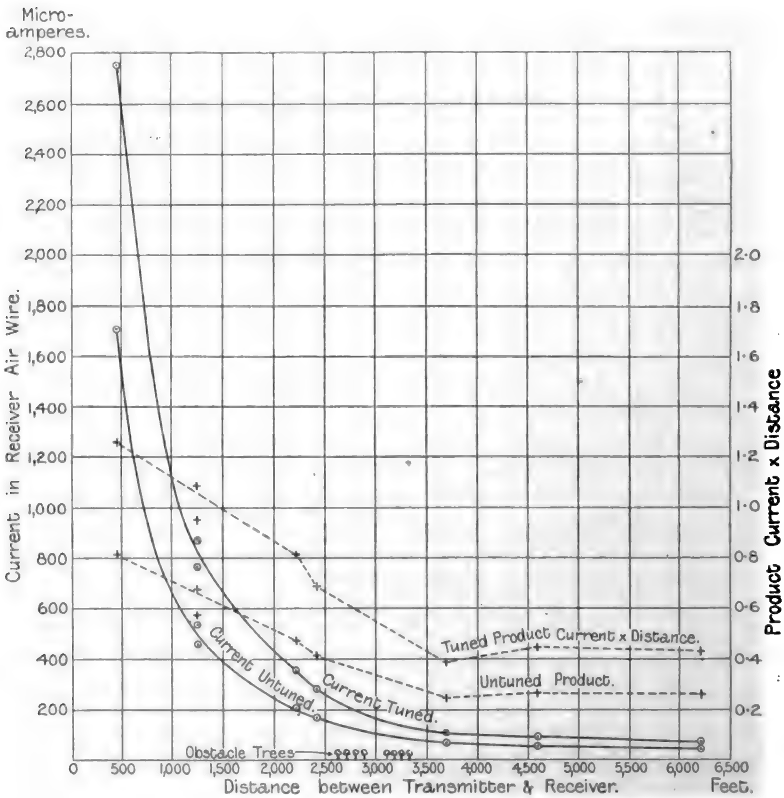
TABLE VI.

Distance between Transmitter and Receiver Varied.

Receiver near Fish Ponds.
Height of Receiver Air Wire, 56 ft.
Height of Transmitter Air Wire, 42 ft.
Spark-gap, 7·08 mm.
Mercury Interrupter. Wave No. 2 (400 ft.).

Distance between Transmitter and Receiver.	Tuned.			Air Wire Only.	
	Current in Transmitter Air Wire.	Current in Receiver.	Product, Current × Distance.	Current in Receiver.	Product. Current × Distance.
Feet.	Amperes.	Micro-amps.		Micro-amps.	
100	0·501	12,320	1·232	7,910	0·791
200	0·507	6,435	1·287	4,043	0·809
300	0·558	4,548	1·364	2,786	0·836
391	0·531	3,013	1·189	1,881	0·736
400	0·541	3,108	1·243	1,969	0·788
476	0·508	2,442	1·162	1,498	0·714
1,260	0·541	715	0·901	433	0·546
457	0·507	2,755	1·259	1,707	0·811
1,245	0·508	766	0·954	460	0·573
1,245	0·508	872	1·085	536	0·668
2,238	0·539	358·5	0·803	210	0·470
2,238	0·550	360	0·806	211·5	0·474
2,420	0·506	283·5	0·686	168·5	0·408
3 700	0·517	105	0·388	66·5	0·246
4,600	0·558	96·5	0·444	57·5	0·265
6,220	0·563	69·5	0·432	42	0·261

Owing to the influence of screening and obstacles it is impossible to say what the law connecting received current with distance actually is, but a consideration of the curves obtained by forming the product of the received current multiplied by the distance and plotting this product against distance, indicates that in these tests the current has decreased in general rather more rapidly than inversely as the distance with increasing distances though nowhere near so rapidly as inversely



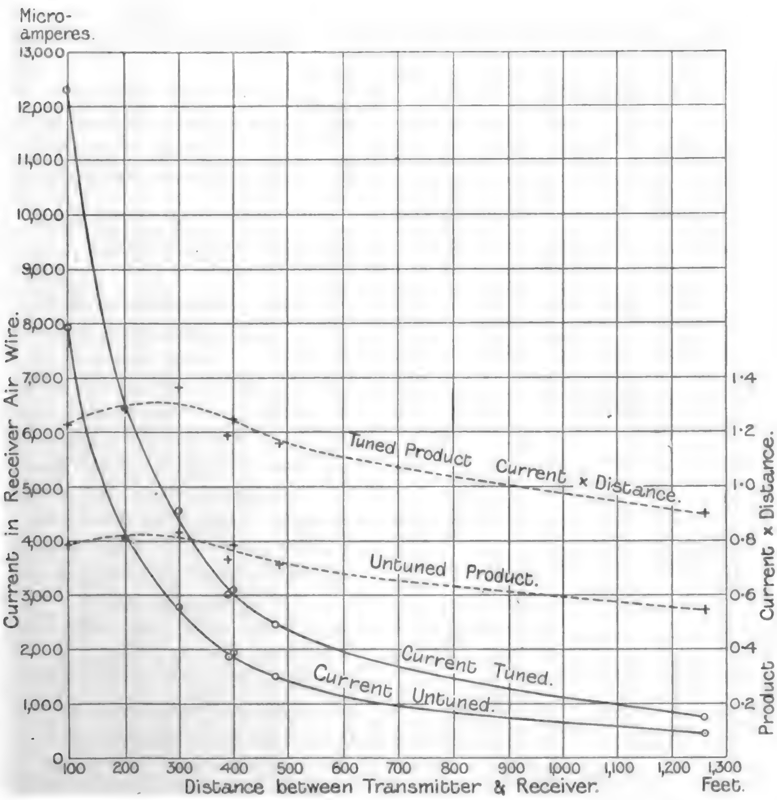
Curves IV.—Distance between Transmitter and Receiver varied. Receiver near Fish Ponds, Position B on Map.

as the square of the distance. The effect of the obstacles, the trees, is very well shown in the product curves as well as the improvement in the conditions when the transmitter gets out in the open again from being directly behind an obstacle. The curves given clearly indicate that at close quarters the rate of decrease is much more rapid than at greater distances. Within the wave length distance there is a very rapid decrease which tapers off to a more uniform rate at about three wave lengths in the case of the longest wave used in the experiments.

For the shorter waves the results obtained were not so regular, but an approximately similar law holds.

Adjustments of Transmitting Apparatus.

To carry out successfully measurements of the strength of oscillations set up in a receiver antenna under the various conditions set



Curves V.—Distance between Transmitter and Receiver varied. Receiver near Fish Ponds, Position B on Map. Short Range Tests.

out in this paper, necessitates very great care in the working of the transmitter to avoid irregularities of action. In spite of all precautions some variations were unavoidable, but they were not of such a nature as would invalidate results obtained if other conditions remained constant. To produce the most regular and uniform strength of oscillations in the transmitter wire it was necessary to give attention to the following points :—

1. To use an interrupter which is capable of uniform and consistent operation.

2. To use a definite adjustment of the spark or discharge gap in relation to the power applied. This gap must not be too short, or erratic multiple sparking is obtained, nor must it be too long, or frequent "misfires" or spark failures then result.
3. To use sparking knobs of a size suited to the capacity and length of spark adopted.
4. To keep the insulation of all parts of the high tension system as nearly perfect as possible, and minimise all brush discharges.
5. To use Leyden jars with good metallic coatings. The nitrous fumes developed during use cause rapid deterioriation of unprotected tinfoil coatings. The jars used were completely varnished over the inside coatings with shellac varnish, except where connections were made.
6. To keep the height and relative positions of the antenna wires, earth leads and earth netting, constant.

The most difficult points to negotiate were those connected with the adjustment of the spark-gap, as, having taken all precautions, sparks would occasionally misfire, or vary in intensity. Owing, however, to the method adopted in observing and recording the deflections obtained on the receiving instrument occasional "misfires" did not necessarily affect the readings, because for each reading a continuous series of sparks, lasting half a minute, was used, and any erratic momentary deviations in the deflections were not considered in recording the mean deflection, the steady value only being taken into account. Apart from this effect, mysterious changes in the spark were often observed. When the transmitter oscillations, as indicated on the thermal ammeter, were below par, it would often be possible to resuscitate the sparks by slightly moistening the discharge knobs. It was also found that for relatively large capacities, such as that used for Wave No. 3, it was impossible to get uniform results with one-inch diameter brass knobs on the discharger, when using a short gap. If, however, the one-inch knobs were replaced by quarter-inch brass rods with rounded ends, a much more uniform effect was obtained for short sparks of, say, $\frac{1}{8}$ to $\frac{1}{4}$ inch, but for longer sparks the knobs were preferable. On the other hand, with the smaller capacities used, the knobs were found suitable under all conditions of spark lengths adopted in the experiments, whilst the rods gave poor results.

As regards the form of interrupter, the most consistent results were undoubtedly given by the Mercury Turbine, if run at speeds less than about 1,500 revolutions per minute. At higher speeds there is a tendency to churn up the alcohol and mercury, forming a mercury emulsion, which seriously interferes with the action of the interrupter. It is also very important to keep the resistance of the primary circuit through the spark coil as low as possible and adjust the current strength by regulating the voltage applied rather than by inserting resistance. The Grisson Interrupter gives a much more rapid series of

sparks, however, and therefore produces a larger deflection on the receiver.

The relative positions of the antenna wire and earth netting is very important. The strongest oscillations were obtained when the antenna was immediately over the middle of the earth netting. In experiments with a transmitter antenna of an inverted L-shape, the reading on the thermal ammeter in the transmitter wire increased from a mean of 0·464 ampere, with the earth netting displaced about five yards from its symmetrical position under the antenna, to a mean of 0·496 ampere with the netting immediately under, an increase of about 7 per cent. in current strength.

Tuning.—The tuning between the exciting circuit and the transmitter antenna, although well defined, was not of the sharpness which can be developed by improved methods of coupling. It was such that the number of turns in the auxiliary inductance used for tuning the antenna might be varied to the extent of about 15 or 20 per cent. without greatly affecting the strength of oscillations. The tuning of the receiver antenna was rather more definite than this. For the different waves used the adjustment of tuning inductances with full heights of antennæ was as follows :—

	Turns of Inductance in Antennæ. Transmitter.	Receiver.
Wave No. 1	12	8
„ „ 2	18	12
„ „ 3	40	32

The total lengths of wire from the top of the antennæ to the earth netting in each case were :—

	Transmitter Wire.	Receiver Wire.
Wave No. 1	96 feet	92 feet
„ „ 2	102 „	96 „
„ „ 3	124 „	116 „

It was from these figures that the wave lengths were deduced on the assumption that the wave was about four times the length of the wire used in the radiating system. For Wave No. 3 it might be thought that a length of 480 feet would be more consistent with the lengths of wire than the 500 feet assumed, but in this case considerable amounts of inductance were inserted in the antennæ, and it appeared reasonable to assume that in such a case the inductance would be increased in a greater ratio than the number of turns of wire on the drum. The reason for the receiver wire being shorter than the transmitter is not very clear, but the difference is within the limits of experimental error. It is, however, possible that the oscillating current in the antenna flowed to earth *viâ* the spark-gap and the Leyden jars, rather than *viâ* the Leyden jar inductance spiral. If this was the case it would be necessary to add more inductance in series with the antenna to tune it to the same period as the oscillatory exciting circuit, hence the longer length of wire. This method of computing the wave

length in terms of the length of wire used is open to error where large aerial capacities are concerned, but in the present instance where the antennæ were formed of single wires it may be taken as sufficiently accurate for a rough approximation.

As an aid to tuning and for indicating the strength of oscillations in the transmitting system, the pivotted thermo-ammeters proved very satisfactory, and they have the great advantage, as compared with hot-wire ammeters of the usual description, that the resistance and inductance which they introduce into the system are practically negligible. As regards the sensibility of the suspended form of instrument used at the receiver, it may be taken that good readable deflections could always be obtained so long as the strength of signals was sufficient to act upon the coherer receiver with the slow sparking interrupter at the transmitter. To increase the range of sensibility beyond this point merely requires an increase of the rate of sparking.

In connection with the question of tuning, a brief series of tests were made at the transmitter to determine whether the Duddell thermo-ammeter used was inserted in the best position in the radiating system. Accordingly one ammeter was fixed permanently in position A, as shown in the diagram (Fig. 1), whilst another was inserted in successive positions *a*, *b*, *c*, *d*, and *e*.

The results obtained were as follows :—

Position.		Current.
a	... ...	0·300 ampere.
b	... ...	0·337 ,,
c	... ...	0·344 ,,
d	... ...	0·355 ,,
e	... ...	0·338 ,,

It will thus be seen that whilst the ammeter was normally connected up in the correct position, the actual antinode of current was not on the wire netting. From this point of view the netting appears to act as a capacity rather than an actual earth connection.

In conclusion, the authors wish it to be understood that the general scheme of operations and many valuable practical details of the experiments were directly due to Mr. Gavey, through whose good offices the necessary official permission has been obtained to publish these results, which they trust may be of some use in advancing the cause of wireless telegraphy.

APPENDIX.

Since the above paper was accepted by the Institution, further tests on the law connecting the received current and the distance between the transmitter and the receiver have been made over a very much more extended range of distances. The experiments were carried out between H.M. telegraph ship *Monarch*, and a receiving station set up alongside the Martello tower at Howth in Ireland.

Three series of tests were made, namely, while (1) the *Monarch*

came south from Scotland and passed Howth; (2) the *Monarch* started from Howth, crossed the St. George's Channel, and entered Holyhead Harbour; (3) the *Monarch* returned from Holyhead to Howth.

The aerial erected on the *Monarch* consisted of four wires, forming the corners of a square of 1 ft. 4 in. side, suspended from a spar hoisted on the top of the main or after mast. The four wires were bunched together at the top and bottom ends, and extended from the end of the spar, 108 ft. 4 in. above the water, to about 13 ft. 4 in. above the deck of the vessel, *i.e.*, 23 ft. 10 in. above the water. From the lower end of the wires a highly-insulated cable was led through the upper and lower decks into the temporary testing compartment by the side of the after cable tank, the apparatus being somewhat below the water line.

The same general scheme of transmitting connections was used as in Bushy Park, Fig. 1, the earth connection being made to the hull of the vessel. The inductance L in the oscillating circuit consisted of four wires wound side by side on a wooden frame 6 in. in diameter so as to form a four-turn spiral, having about $\frac{5}{8}$ in. pitch. Each strand consisted of sixty-one wires, five mil. diameter stranded together and silk covered. A connection was teed off this inductance-spiral and connected to the aerial. By altering the position at which this connection was teed off, or by using the whole of the spiral, the coupling could be varied.

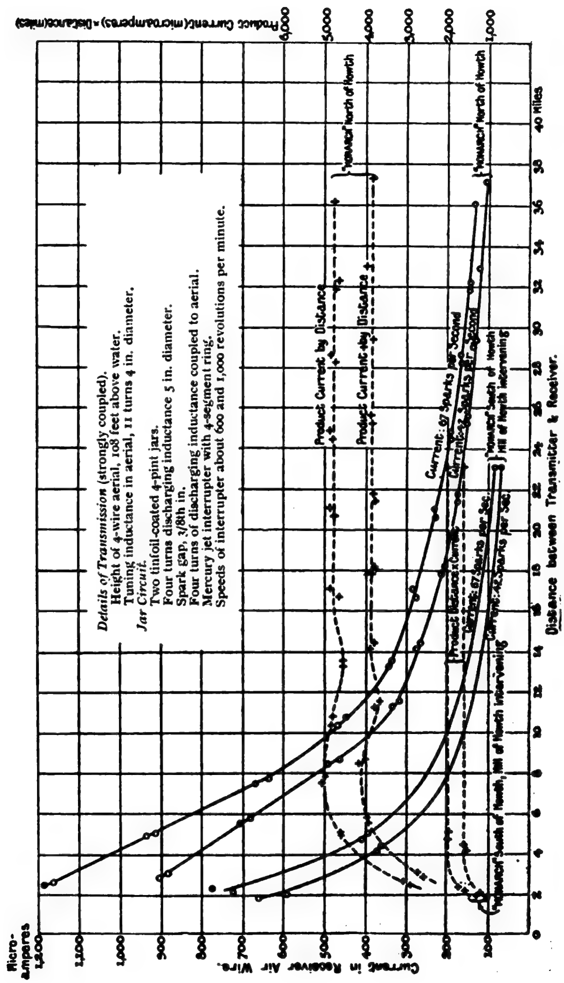
The mercury turbine interrupter was used for all the tests, at two different rates of sparking, namely, about forty and sixty-seven sparks per second. These values were chosen as affording about the maximum difference in rate at which the interrupter could be run so as to give uniform sparking.

The aerial system at Howth was constructed in a similar way to that on the *Monarch*. The height to the top of the four wires was 156 ft. 5 in., and to the bottom end of the four wires 63 ft. 6 in. from the ground. From this bottom end a cable was led into the Martello tower and connected to a sliding condenser used for tuning purposes, the other terminal of which was connected through the thermo-galvanometer to earth. The "earth" consisted of four strips of 1-in. mesh wire-netting, 31 ft. long by 4 ft. wide, laid on the ground in the form of a cross immediately beneath the aerial wires.

Owing to the very large range of currents in the receiver air wire that it was necessary to measure; two thermo-galvanometers were used at Howth so that one instrument could have its sensibility altered whilst the other was in use.

Results.—The first series of measurements was carried out with the *Monarch* approaching Howth on her journey south down the Irish Sea. For these tests the transmitter was strongly coupled to the aerial by making the connections so as to include the whole of the inductance spiral L, as shown in Fig. 1. Before commencing the measurements it was necessary to tune the receiver to suit the signals sent by the *Monarch*. This adjustment was made, and measurements commenced at a distance of 37 miles. The results are plotted in Curves VI.

At long distances when the relative change in the distance and the received current is small between one signal and the next, the means of each set of four signals have been taken and plotted on the curves as a single point; at shorter distances each individual observation has been plotted giving a cluster of points on the curve.



Curves VI.—*Monarch* coming South and passing Howth.

The course taken by the *Monarch* on this and the following journeys is shown in Fig. 3.

The second and third series of measurements were carried out while the *Monarch* made a special trip for the purpose from Howth to Holyhead and back. The first set of signals was transmitted while the

vessel lay at anchor as close as practicable to the Howth Station. The vessel proceeded dead slow for the first seven or eight miles, and then continued her journey at full speed, signals being sent at regular intervals. Owing to a mist which prevailed and to the strong tides in the Irish Channel it was not always possible to ascertain accurately the distance of the vessel from Howth. The results obtained on these two journeys are given in Curves VII. and VIII., measurements being made over the whole distance to Holyhead Harbour, namely, up to sixty miles.

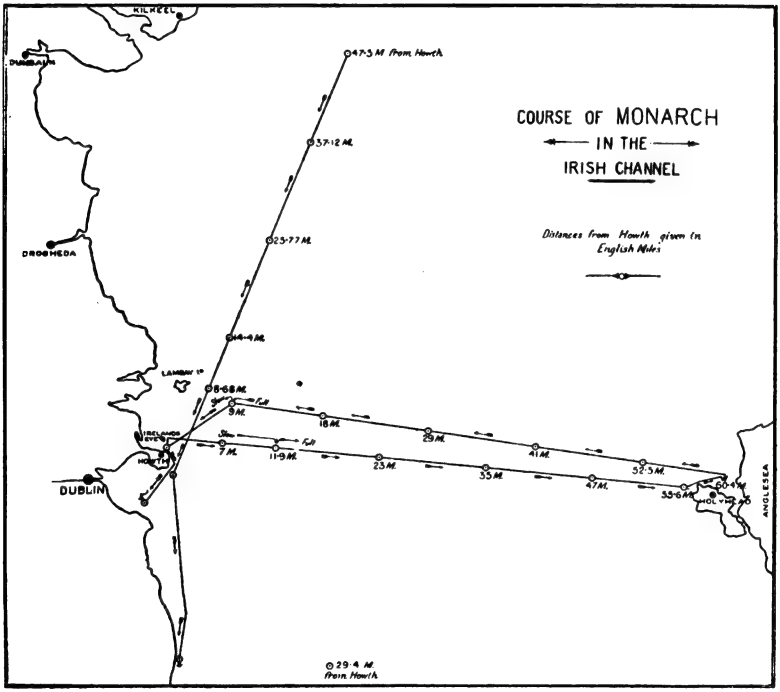
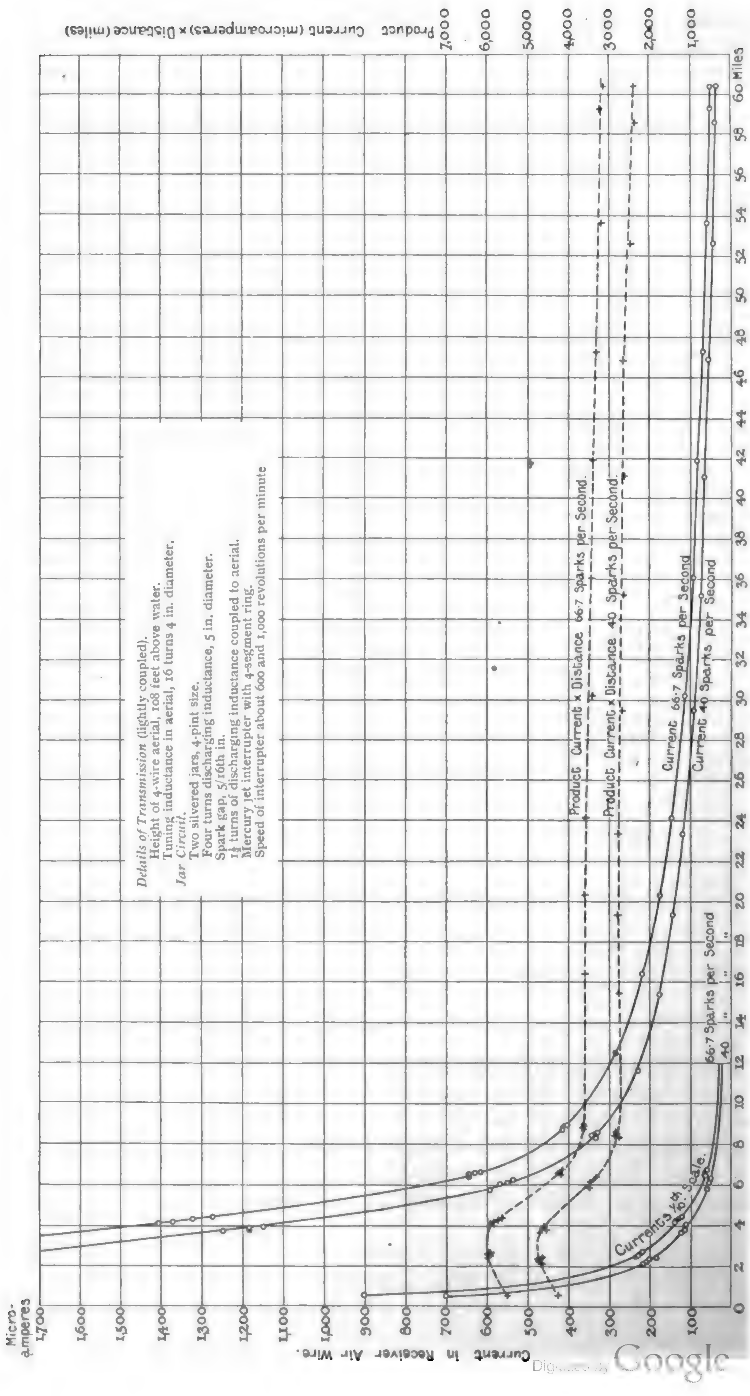


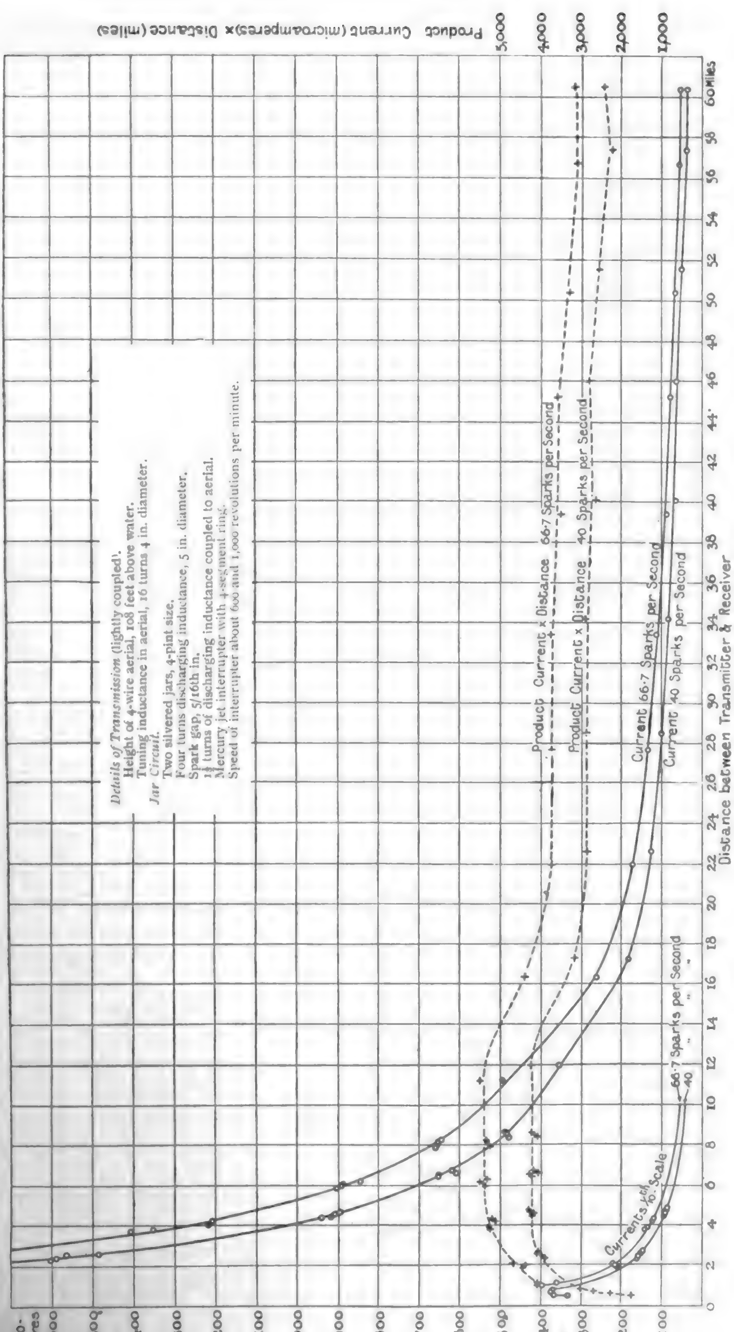
FIG. 3.

A much weaker coupling between the oscillating-circuit and the aerial was employed for this series of observations, only $1\frac{1}{2}$ turns of the inductance L being connected to the aerial. The tests which led to this choice of coupling are described later. The tinfoil-coated jars used in the first set of experiments were replaced with jars having chemically deposited silver coatings for the second and third series of measurements.

All three tests prove that, at any rate, for fairly long distances the current in the receiver air wire is almost exactly inversely proportional to the distance between the transmitter and receiver, so that the



CURVE VII.—*Monarch* crossing from Howth to Holyhead.



CURVE VIII.—*Monarch* returning from Holyhead to Howth.

product of the received current by the distance is practically constant. The curves, however, show a few peculiarities of which some explanation may be suggested. On comparing the curves for the journey south with those for the Howth-Holyhead course it will be seen that there is a considerable difference in the strength of received currents at equal distances—the latter being much weaker. This is partly accounted for by stronger transmission in the first case, a spark gap of $\frac{3}{8}$ inch against $\frac{5}{16}$ inch in the latter case being used in the closed oscillating circuit. The transmission was not, however, greatly weakened on this account judging by the readings of the ammeter in the transmitting aerial. The wave length used in the later tests was somewhat longer than that previously used, but though this fact might weaken the transmission it would also have the effect of increasing the received currents at Howth, because the waves used were throughout rather short for the Howth aerial, it being necessary to introduce a condenser in series with the aerial for tuning purposes at that station. The following table gives the actual currents transmitted and received at a distance of 30 miles on each of the three courses :—

Journey.	Distance. Miles.	R.M.S. Current Transmitted.	R.M.S. Current Received.
South (April 8th) ...	30	2·83 amps.	160 micro-amps.
Howth to Holyhead (April 11th)	30	2·72 „	115 „
Holyhead to Howth, return journey (April 11th)	30	2·8 „	125 „

From these figures it will also be noted that more current was received on the return than on the outward journey, between Howth and Holyhead, and it is thought that the same reason accounts for both peculiarities, viz., the reflection from the Hill of Howth, immediately behind the receiving station, which would tend to strengthen waves received from positions to the north of Howth. The course of the *Monarch* on the return journey was considerably north of the outward course, as will be seen from the sketch map. The assumption of reflection by the Hill of Howth assists also in explaining other peculiarities. It accounts for the difference in the received currents on the outward and return journeys, and it may explain the slight tendency of the product curves in both to slope downwards at the longer ranges, the assumption being that the vessel is gradually getting away from the field of reflection. In the journey south it will be noticed that this slope is absent, the product "distance by current" giving a straight horizontal line at the longer ranges. Another possible, but apparently less probable, explanation of the sloping

tendency is that while the cross-Channel runs were made in daylight and in a misty, damp atmosphere, the up-Channel course was made in the night and early morning hours with a clear, frosty atmosphere. There may thus have been some wave absorption in the former case which was absent in the latter.

A probable explanation of the irregularity in the product and current curves on the commencement of the return journey across the Channel is not easily seen, but possibly the reflection from land on the Holyhead side had something to do with this.

In the down-Channel or southern course the only striking irregularities to be noticed on the curves are the depressions on the upper product curves occurring between 10 and 15 miles range, which correspond to less noticeable irregularities in the current curves themselves. It is thought that the effect is due to interference by reflection from Lambay Island, which rises to a considerable altitude and was in a position relative to the *Monarch* likely to produce interference. That is to say, it appears likely that the direct wave propagation from the *Monarch* was interfered with at Howth by the diverted or reflected propagation *viâ* Lambay Island, which would reach Howth in a different phase.

At the close ranges the effects of reflection were so pronounced that the magnitude of the current received evidently depended as much on the actual position of the vessel as on its distance away. The effect of distance was overshadowed by the effects of reflection from the surrounding high land and the island, Ireland's Eye. For this reason it is not possible to draw conclusions regarding the relation between current and distance at the very close ranges. The product curve undoubtedly reaches a maximum and then drops, as in the Bushy Park experiments, but the distance at which the change would occur for unobstructed waves cannot be stated.

On account, no doubt, of these reflection effects the curves obtained for the outward and return journeys across the Channel show very pronounced differences at ranges closer than 17 or 18 miles. On the return journey the *Monarch* pursued a course which carried her considerably north of the Howth Station, and thus no doubt placed herself in the direct path of reflection from the Hill of Howth at a much longer range than in the outward journey.

On the longer ranges, however, the results are very conclusive. There can be no doubt that the received current is inversely proportional to the simple distance. This is shown accurately in the down-Channel curves, and is only a few per cent. out for the cross-Channel curves, there being ample explanation even for this small discrepancy.

The effect of screening was very well shown when the *Monarch* was coming south, and passing the Hill of Howth (Curves VI.). The received current gradually increased in strength until the vessel approached within twelve or fourteen miles of Howth. As the vessel approached nearer the increase in the current became more and more rapid, until the radiation was cut off by the Hill of Howth intervening between the two stations. The readings obtained after the vessel had

passed this point are shown by separate curves on this sheet. At a distance of twenty-three miles the screening reduced the received current in the ratio of 85 to 210.

TRANSMITTER COUPLING VARIED.

Whilst the *Monarch* was proceeding with her ordinary repairing duties some tests were undertaken to determine the best coupling to use on the Howth-Holyhead experiments. The tests were carried out by altering the points on the inductance L, to which the conductor leading to the aerial was connected. Preliminary tests indicated that four turns and three turns coupled were excessive. The results with two turns and less coupled, which were obtained at a distance of about six and a half miles, are given below :—

Turns Coupled.	Current in Transmitter Air Wire, Amperes.	Current in Receiver Air Wire.	
		Tuned Micro-amps.	Air Wire only. Micro-amps.
2	2·21	313	155
1·5	2·17	333	154
1	2·02	334	154
0·5	1·66	279	118

As the coupling was diminished the received current increased up to a certain point, and the tuning at the receiver became sharper, as shown by comparing the currents received in the tuned and untuned conditions. The 1·5 turns coupled was adopted for the Howth-Holyhead trip as giving about the best result at the receiver.

EARTH CONNECTIONS VARIED.

The superiority of the netting "earth" mentioned in the report was again confirmed.

Three different methods of earth connection were available at Howth :—

(1) The wire netting laid on the ground already mentioned.
(2) A coil of wire dropped into the well of water in the basement of the tower.
(3) Direct connection to the iron sheathings of the submarine cables across St. George's Channel.

With the wire netting the received current was 352 micro-amperes, the tuning on the receiver being sharp and well defined.

With the well "earth" the received current dropped to 306·5

micro-amperes, the tuning was less sharp, but the maximum received current was still obtained with the same tuning adjustments.

With the cable sheathings the received current was still less—namely, 211 micro-amperes. In this case the tuning was much less clearly defined. It was also necessary to alter slightly the tuning adjustment at the receiver.

With the "earth" made by connecting the wire netting and the well in parallel, the received current was 313 micro-amperes, but the tuning was not sharp.

As an "earth" for ordinary telegraphic purposes the cable sheathings here used are excellent, but as an "earth" for wireless telegraphy they were a failure from all points of view.

Resistance of Measuring Instrument Varied.

This test was carried out in a similar manner to that described in the paper. With the receiver tuned the following formula was found to fit the results :—

$$\text{Current (tuned)} = \frac{0{\cdot}0364}{r + 60}.$$

The *Monarch* was anchored in Kingston Harbour at a distance of $6\frac{1}{2}$ miles, during the above experiments, the Hill of Howth intervening between the *Monarch* and the receiver. The weak coupling was used for these tests.

Effect of the Rate of Sparking.

With the strongly-coupled method of transmitting the ammeter indicated a R.M.S. current in the transmitter aerial of 2·31 amperes for a rate of sparking of 42 per second; an increase in the speed of the interrupter to give 67 sparks per second, keeping the spark-length constant, increased the R.M.S. current to 2·83 amperes. Thus although the rate of sparking was changed in the ratio of 1 : 1·60, the current in the serial only altered in the ratio 1 : 1·22. Using the weak method of coupling, a similar result was obtained. In this case an increase in the spark rate in the ratio 1 : 1·67 caused the current to increase in the ratio 1 : 1·30. It is to be noted that in both cases the R.M.S. current in the aerial varied approximately proportional to the square root of the rate of sparking. This also applies to the current in the receiver aerial. If we now wish to consider how the R.M.S. current in the aerial during the train of oscillations produced by each interruption of the current in the induction coil is affected by the rate of sparking, we must multiply the observed currents by the square root of the ratio of the whole time between one spark and the next to the time the train of oscillation lasts. Assuming that the time each individual train of oscillations lasts is unaffected by the spark rate, we see that the R.M.S. current in the transmitter or receiver aerial produced by each interruption of the coil current was practically independent of the spark rate.

Verification of Tuning of Transmitter.

As mentioned in the paper, the air wire of the transmitter was tuned to suit the closed oscillating circuit by varying the self-induction, H, in series with it until the deflection of the ammeter, A, attained its maximum value. To test whether this adjustment also gave the maximum current at the receiving station, a series of tests were made by altering the self-induction in the aerial by a few turns at a time, and recording the received current. It was found that the current in the receiver air wire was a maximum for that value of the tuning self-induction in the transmitter air wire which gave the maximum current through the transmitter ammeter, thus confirming the method used of adjusting the tuning.

Day and Night Transmission.

An attempt was made, while the *Monarch* remained at anchor in Kingstown Harbour, to determine the difference in strength of signals received during the daytime and at night. No difference was observable which could be traced to greater absorption during daylight, and it appears certain that if such a difference exists it is less than 1 per cent. This confirms Marconi's statements, that the difference is not observable at close ranges and with relatively short waves.

The "zones of weak signals" to which Captain Jackson has made reference were also not observable. It is possible that specific climatic conditions are necessary to develop this effect. The curves plotted on the different runs of the *Monarch* do not show any recognisable tendency in this direction.

No effects directly traceable to atmospheric disturbances were observed while taking the readings at Howth. Probably the effect they produce on the thermo-galvanometer is too small to be noticeable owing to their transient nature, but it should be remarked that they are not so intense nor so frequent at the time of year at which these tests were made as in the hotter summer months.

The authors wish to express again their indebtedness to Mr. Gavey, and to thank Messrs. A. C. Booth and F. Addey for their assistance with the tests.

Mr. Gavey.

Mr. J. Gavey: It is, I think, a mere truism to state that the development of any of the applied arts is largely dependent on the possibility of effecting accurate measurements. When wireless telegraphy was initiated, the possibility of effecting accurate measurements, whether at the transmitting or at the receiving stations, was very limited. Wave-lengths had to be known, capacities and inductances of vertical wires had to be measured, things that in theory might be calculated readily, but in practice the calculations were very liable to be upset, through the proximity of stays and other means necessary to keep the antenna extended to the requisite height. However, as time went by means were designed for carrying out effective measurements at the transmitting station. An apparatus is now on the market which admits of

accurate measurements of wave-lengths; and measurements of capacities and inductances of all types of vertical wires have been effected with more or less readiness. But until recently I do not think any one has solved the difficulty of measuring the energy at the receiving station. I have had this in my mind for a very long time, and I had occasionally discussed the subject with Mr. Duddell, so that when he came to me and said that he thought he had an instrument that would effect the measurements we had in view, I was very pleased to move the Postmaster-General to afford him the necessary opportunity for his experiments. I think this instrument meets a want that has long been felt. One eminent authority on wireless telegraphy, Dr. Fleming, in a recent paper stated that the want which was most keenly felt was the need of an instrument that would measure the energy at a receiving station of a wireless system. This instrument does the work, and you have seen for yourselves that it does it in a most admirable manner. It has proved conclusively many things of which we had a more or less general idea. When I referred just now to the progress of wireless telegraphy, I did not want in any sense to diminish the credit that is due to those who have made such enormous strides in wireless telegraphy in the last two or three years; but their means of measurement, so far as the receiving currents were concerned, were of the crudest. All those who have experimented with coherers or with telephones as the measuring instruments must have realised how unsatisfactory they are as such and how much the accuracy of the measurements depends on the personal equation of the observer. With these difficulties in view, I again say that it is surprising that such progress as has been made has been realised. The measurements of the received energy at varying distances are very satisfactory; they confirm the views we held and which were based on the crude measurements that I have referred to. How far the linear law will extend is another question. Mr. Marconi has told us that in long-distance wireless telegraphy the effects vary very materially by day and by night, after a certain distance has been reached. I do not know whether Mr. Duddell will be able to adapt his instrument for use on board ship; but if he can do so, and if measurements can be extended, not over distances such as that between Holyhead and Howth, but right across the Atlantic, I think it possible that the means of overcoming the difficulties that Mr. Marconi has experienced in the past may be realised. It certainly will be highly interesting to note at what particular point this linear law drops off and some other unknown law comes into play. Again the use of wire netting instead of the earth is extremely interesting. Of course the use of wire netting for earth has been known for a long time; in fact, in Mr. Marconi's very early experiments across the Bristol Channel I remember noting myself that when the coherer was in a receiving condition you could remove the earth connection and still receive signals equally well by putting your finger on the coherer terminal. The wire netting or the body of the experimenter evidently acted as a condenser. The measurements taken also illustrate very forcibly the different values or the different effects that may be obtained by Mr. Gavey.

Mr. Gavey. varying the arrangement of the antennæ or the aerials. It has been long known that with moderate energy available, if you only have a certain amount of wire to use, you will get the best possible results by extending that wire vertically; on the other hand, there is a limit to the height to which you can extend a wire or maintain it with security. I think the actual measurements showing how the wire can be best disposed by extending it horizontally at a certain height are extremely interesting.

Captain Jackson. Captain H. B. JACKSON, R.N., F.R.S.: It has been a great pleasure to me as a practical wireless telegraphist to listen to this paper to-night. I wish we had had more of them some years ago, to have helped us out of a good many difficulties. These experiments have been very systematic, and they confirm experiments I have carried out—and they are a good many, but not so systematic as these—and are absolutely in agreement with them, without any exception. There is nothing I can criticise. I notice the authors have been very reticent indeed in giving any explanation of some of the phenomena, and if I may I will mention one or two. On pages 326 and 330 they deal with varying the transmitting and receiving-wires. A receiving-wire 56 ft. long for a 500-ft. wave is a bad length for getting a good effect from that wave, 56 ft. being only about one-ninth of the wave-length. If it had been about one-fifth I think the authors would have got better results, and probably would have been able to get the value of the *k* constant very much more accurately than they have been able to do. They seem to have got it accurately in the tuned experiments, but in the untuned with a 56 ft. wire with the wave-lengths used I hardly think they could get it. It is noticeable in that same length of wire where the shorter wave-length was used, that the maximum current in the receiving aerial was very greatly increased—I think it was increased in one case from 82 to 270—that is to say, with the shortening of the wave a very much stronger current was measured. With the tuned system the increase in current is small. The tuning in this case simply means lengthening the aerial wire and bringing the receiver to the position where the current is at the maximum.

In regard to the length of the transmitting-wire, I quite agree with the authors that the capacity is increased by increasing the length of the wire, and therefore the amount of energy stored is increased, and consequently the energy radiated and that received. Varying the shape of the aerial wire does not to any appreciable extent alter its capacity, but a certain amount of radiation is lost; that loss is very small, and it is due to the loss in the effective height. I think the experiments are fully in accord with the theory that it is the length of the transmitting-wire rather than its height which determines the energy radiated, but the greater the effective height the better. With regard to the earth connection I think there is nothing more difficult in wireless telegraphy. They had been a great puzzle to a great many of us. Fortunately on board ship, where most of my experiments have been carried out, we can use the hull of the ship, and so always obtain good earths. I have not experienced difficulties except on shore

Captain Jackson.

stations, and there, as the authors have also found, we have had some very peculiar results. I think the rolling up of the netting in Experiment 8, Table III. may increase its weight and pressure per square foot on the ground, and so perhaps make rather a better connection but I only throw this out as a suggestion, that it may be that the extra weight of the wire on the ground may have made a better earth connection. I am distinctly in favour of the theory that the earth acts as a conductor for these waves of alternating E.M.F.

As regards the length of the aerial wire, I have frequently experimented with balloons and kites at great distances, and I have never found any appreciable increase in distance when the length of the aerial was more than half the wave-length. If you have the aerial approaching a half-wave length, it is absolutely essential to put a condenser in at the bottom of the aerial, between it and such a receiver, as was used in these experiments. I think the lengthening of the aerial can be best obtained by stretching it vertically as high as you can, and then horizontally from the top; in that way you may get a very long aerial, nearly half the wave-length. I am not talking of waves of a mile in length, but of ordinary waves of 500 to 1,500 ft. in ship installations. I think you can get the best effect by making the length of the receiving aerial half the wave-length and putting a condenser at the bottom of it between it and the receiving instrument. The results obtained by varying the resistances and distances as done by the authors are extremely valuable, and I am sorry I have not had time to study this part of the paper more fully.

I think they are one of the most useful set of measurements that have been made in wireless telegraphy. The whole of these experiments bear out all the theories I have formed—after many years' experience—especially the theory that the distance varies directly as the power—that is to say, if you double the power, you get double the distance, within ordinary distances over which the curvature of the earth has not any great effect, but not at too close distances, as the authors have very clearly shown by means of their experiments. I attribute the hump in the curves in the Holyhead-Howth experiments principally to there being two transmitted waves. I do not know of any transmitter that sends out one pure sine wave; they always seem to have superposed waves, and if they have two or more waves going out together, you will find that the curves of maximum and minimum effects will be in humps, and that they will give you the maximum power where you may not expect it.

Recently in the Naval Service we have been working very hard to get a good wave-length meter, and I think we have at last succeeded. Everything has been standardised. We use air-condensers which have been calibrated by means of standard air-condensers, and we use inductance coils which have been also carefully calibrated; and we think now we are quite capable on board the *Vernon* and her tender of measuring wave-lengths within 2 or 3 per cent., and with the Duddell thermo-galvanometer I hope to do even better than that. The tender can go round the coast and measure the wave-length at any of our stations.

Captain Jackson.

The distance up to which we have measured wave-lengths reaches 1,000 miles, and we are quite capable now of measuring them accurately up to any distance at which we can receive fairly strong signals. I may say that we have also succeeded in cutting out interference to a greater extent than has ever been done before. The last report I have is that on board the ship at Portsmouth we can receive from Poldhu on an aerial wire on the foremast, at the same time that another aerial on the mainmast is sending out strong signals, and yet those strong signals can be absolutely tuned out sixty yards off at the foremast.

Dr. Sumpner.

Dr. W. E. Sumpner: I should like to congratulate the authors on the admirable experimental lecture we have had, and on the valuable experimental measurements contained in their paper. Two laws in particular I think especially important. One is the law of the current generated in the receiving-wire, and its variation with the resistance and with the self-induction of the receiving-wire. The law arrived at is what was to be expected from a simple approximate theory, but at the same time I think it wonderful that the experiments have been accurate enough to prove it. The other law which they have proved is the very important one of the constancy of the product of the current and distance. I rise really not to criticise, but to draw attention to the interpretation of the results in amperes, volts, and watts. Although Mr. Duddell is perfectly aware of the point, I do not think he has made it sufficiently clear in the paper that the current which he gives as the root mean square current is not to be interpreted as the root mean square of the current while the oscillation lasts. Mr. Duddell has pointed out clearly on page 334, in reference to the voltage, that the mean is the root mean square voltage taken over the time the wave-train lasts, plus the time between it and the next set. He then goes on to give as a reasonable estimate that the time interval between the trains is about three thousand times the time the actual train lasts. He then multiplies—for some reason that I should like him to explain—0·12 by the root of 3,000, in order to get the voltage. Now it seems to me that the number ought to be multiplied by 3,000 and not by the root of 3,000, in order to get the voltage of the train while it lasts. I do not see why he introduces the root.

The point is an important one, of course, because whereas Mr. Duddell works out his voltage to an average of 6·6 while the train lasts, I consider that while the train lasts the average voltage is three thousand times 0·12, that is to say, 360. If I am right in that contention, it applies not only to the voltage but to the current, and as the current in the transmitting wire in most of the cases he gives lies between 0·5 and 0·7 ampere, these numbers will have to be multiplied by the same factor, three thousand, to get the current in the aerial wire while the oscillations are lasting. The instruments with which Mr. Duddell has measured the current give the root mean square of the current during the time he is making the measurement—that is to say, as he himself points out, during the interval between one spark and the next. Now, there are two points in connection with this to be considered. One is the influence of altering the frequency of the

Dr. Sumpner.

spark. I was surprised to find from the paper that working with two interrupters, one producing sparks at about six times the rate of the other, the current in the transmitter only varied in the two cases from about 0·5 to 0·7. I could not understand that, as it seemed that the ratio of these numbers should be six, or at all events the root of six, according to the authors. But Mr. Duddell to-night has offered an explanation, which he pointed out in connection with the experiments on the first sheet, of curves on the wall. In the one set of tests there were 40 sparks per second, and in the other case 66 sparks per second, but the root mean square of the current, instead of being altered in the ratio of 40 to 66, was affected to a very much less extent. Mr. Duddell stated that this result was probably due to something happening at the oscillator and affecting the train of waves; and that no doubt is a possible explanation. But supposing we consider only one particular oscillator producing sparks at a given rate, there is no doubt that the interval between the sparks is immense, as compared with the interval during which the oscillations last. That not only affects our estimate of what the current is, and of what the voltage is, but it is very much more important to notice that it also affects our estimate of what the power in watts is. If we average the current and the volts over a thousand times too great a time, we estimate the current at a thousandth of the true amperes, the voltage at a thousandth of the true volts, and therefore the watts at a millionth of the true watts; moreover, so far as energy is concerned, we have to take into account the alteration of the time during which we suppose the power to last, and have to introduce another factor of a thousand on this account, so that the net result is that we estimate the energy per train of waves at a thousandth of what it really is. It is very important to know what really happens in the oscillator while the oscillations take place. The numbers which Mr. Duddell gives on page 336 for the watts—100 and 200—according to my view, ought to be multiplied by 3,000. Of course this leads to a very great estimate of the number of watts, but it is not at all unreasonable in my view to assume that the power in watts, while the power is lasting, is something like a hundred kilowatts rather than a hundred watts. The momentary power may be immensely great compared with the average power supplied to the induction coil. What we are really dealing with in wireless telegraphy is a kind of lightning under control. We have to deal with the same characteristics as in the lightning flash. The flash lasts but a very short time, but while it lasts the current, the power, and the light are each immense. Similar properties I believe exist with regard to these oscillations.

(*Communicated.*) On referring again to the paper, I now acknowledge that Mr. Duddell was quite correct in regard to his mode of applying the factor, and that my view was mistaken. If a and v are the amperes and volts corresponding with the instrument readings, and if the interval between the sparks is 10,000 times the duration of a wave-train, the amperes and volts of the wave-train are respectively 100 a and 100 v, and the watts (assuming unity power factor) are 10,000 av.

Dr. Sumpner.

The energy of each wave-train is either the power *av* multiplied by the time interval between the sparks, or 10,000 *av* multiplied by the duration of a wave-train. There is, of course, considerable uncertainty as to the true ratio of the spark interval to the duration of a wave-train, and there are further complications due to varying amplitude, etc. There does not appear to be much prospect of determining the energy and power of the wave-trains until ballistic, or oscillograph, instruments are made sufficiently sensitive to indicate the effects due to a single spark. At the same time it appears to me highly probable that the voltages set up in the receiving-wire are much greater than those indicated by the authors (on page 334). It must be remembered that the minute sparks associated with wireless telegraphy always indicate high voltages, however negligible the power may be.

Professor Ayrton.

Professor AYRTON: I think perhaps it would be better if, with your permission, Sir, Mr. Duddell in his reply gave a very short description, for the benefit of those who are not familiar with it, of the thermo-galvanometer that he has been using. Of course it has been published, but I fancy there are many here who do not know at all what is inside that pot. If he were to tell us further what the instrument was developed for originally, it would be really interesting, for it was not developed for wireless telegraphy at all.

Dr. Fleming.

Dr. J. A. FLEMING, F.R.S. (*communicated*): Whilst concurring in the opinion expressed as to the interest of these experiments, I cannot help thinking that the authors of this paper would have bestowed upon it more value if they had given the absolute value of the inductances and capacities of the different portions of their transmitter and receiving arrangement.

The authors make mention in one place of a capacity used as consisting of "one 4-pint jar half covered with tinfoil," and in another place a capacity is spoken of as consisting of a "one 4-pint jar completely covered with tinfoil." Such a method of describing the capacity of a Leyden jar may be pardonable in the catalogue of an instrument maker, but it is certainly a little vague as a definition of a capacity employed in quantitative wireless telegraphy measurements. Also we have inductance coils simply described as consisting of so many turns of certain sizes and wires. The measurement of the capacity of Leyden jars or of inductances as small as a few microhenrys has now been brought to great perfection, and it is not a matter of any greater difficulty to measure the capacity of a Leyden jar than the resistance of a yard or two of No. 16 copper wire. I have myself described in many places methods for making these measurements, which are in every day use in my own laboratory by students. It should be pointed out, however, that Leyden jars are not a very suitable form of condenser for quantitative wireless experiments. The high-frequency capacity of a glass Leyden jar is always greater than its low-frequency low-potential capacity by a somewhat undetermined amount due to glow discharge at the edges, and also there is an uncertainty as to the exact dielectric hysteresis.

Dr. Fleming.

I have shown in another place that the best results are obtained by the use of metal-covered ebonite sheets immersed in oil; and Dr. Drude has shown that the only method of eliminating altogether the effects of dielectric hysteresis is to employ a condenser formed of metal plates immersed in highly insulating oil.

Again, it has been pointed out by me that in the use of bare wire spiral inductances there is always an uncertainty as to their high-frequency inductance value due to the dielectric current passing between the turns, and therefore some precautions are necessary in drawing conclusions as to the real inductances and capacity employed in a high-frequency oscillating circuit.

Furthermore, the authors appear to me to have estimated their wave-lengths in an erroneous manner. Unless I misread their paper, they seem to assume that if to the length of the aerial is added the total length of the inductance in series with it and the sum multiplied by 4, it will give the wave-length. This is not the case. It has been shown by Mr. Macdonald in his book on Electric Waves that the wave-length of a simple linear Hertz oscillator is 2·53 times the length of the oscillator, and this has been experimentally confirmed by Cole. Hence we may infer that the wave emitted from a simple linear Marconi, aerial is more nearly five than four times the length of the aerial, but if an inductance coil is added in series with it, this in addition produces a complication, and the true wave-length can only be ascertained by means of an instrument I have called a Cymometer. I have devised several forms of the instrument, with which it is quite easy to measure the length of a wave, from 300 to 3,000 feet or more with an accuracy of 1 to 5 per cent. Hence the authors could quite easily have ascertained experimentally the real frequency in their oscillating circuit. The main object of their experiments seems to have been to ascertain the relation between the distance over which they could work and the current passing in and out of the earth at the receiving and transmitting stations. It must be remembered, however, that the hot wire ammeter measures the root mean square value of the oscillations; hence its indications are dependent upon several variables—viz., the number of groups of oscillations per second, the maximum value of the current oscillations in any train and their logarithmic decrement. Accordingly, it is possible to have groups of oscillations which would give the same indication on a hot wire ammeter, and yet differ very much in group frequency and logarithmic decrement and maximum value, and hence in their effect upon different kinds of wave detector. Very different effects would be produced upon coherers, magnetic detectors, thermal detectors, or vacuum tube detectors by currents in the aerial having the same root mean square value.

The authors complain in some places of a difficulty in obtaining constant discharges, but that appears to be only because they have restricted themselves to the use of a ball discharger. It has been known for a long time, and has been particularly shown by Professor Pierce, that the most constant results are obtained when using a

Dr Fleming.

Cooper-Hewitt mercury discharger, and in all quantitative work my own experience is that it is far better to use an alternating current than the current from an induction coil.

One interesting result obtained by the authors, however, appears to be that the root mean square value of the current passing in and out of the receiving aerial from the earth in some cases varies almost inversely as the distance between the transmitter and the receiver. The curves they give in their diagrams IV. and V. for the current are roughly rectangular hyperbolas, but it must not be concluded from this that the same results would be obtained with another detector ; the results are good only for the precise circumstances of the experiments conducted. In any further experiments, however, it is much to be hoped that the authors will abandon the method of describing capacities in pint Leyden jars and inductances in so many turns of wire, and give absolute measurements in recognised units for the various quantities involved in the construction of their apparatus. The value of such experiments lies in the means they give us for checking and testing theories; but if the quantitative data are absent, then this most useful quantity is absent also.

Mr. Pochin.

Mr. E. A. N. POCHIN (*communicated*): It is remarkable that so much confusion is common on the subject of earth connections, as the matter is really a very simple one. Earths can only be of two kinds, viz, (1) conducive, and (2) inductive (condenser), for there is no other possible means by which you can connect to earth.

The authors' inference that the wire netting was an inductive "earth" is undoubtedly correct, and this is confirmed by their remarks on p. 330, where we find that after a shower the current fell off by some 2 per cent. Had the netting been a conductive earth, the moisture must necessarily have improved matters ; but being an inductive earth the moisture, instead of assisting, simply becomes a leak across a condenser. If, as I suppose, the result was unexpected, it affords evidence both of the accuracy of the instruments and of the faithful way in which the readings were recorded.

The obvious conclusion is that unless you can get a really good conductive earth, such as the hull of a ship, you had better use an inductive earth—it is the mixed earth which is so pernicious. From this point of view the sheathing on the telephone cable should have been especially bad, as was found, since it was composed of distributed leak in parallel with distributed capacity.

A paper by Count Arco * throws much light on the question of "coupling," and it is shown that such a system as Fig. 1 cannot give a pure wave, as the aerial has two different paths to earth—(1) *viâ* the self-induction L, and (2) *viâ* the spark gap and condenser F, giving rise to a mixed wave consisting of long oscillations through L, and shorter oscillations through F.

If, however, the aerial is tapped off at a point approximately midway along L, the two paths then have equal impedance and a true wave results. This is in effect what the authors do when they change from

* *Electrical Review*, vol. 53, p. 437, 1903.

Mr. Pochin.

their rigid to their weak coupling, and I would suggest that the improved transmission which resulted from the change should be attributed to the sharper tuning with the purer wave.

If the capacity of F were large and the self-induction L small, relatively to the aerial, the variation introduced would be small; but it should be noticed that the influence of the path through F must in any case be to reduce the apparent length of the aerial; and this, I think, affords the real explanation of why the transmitter aerial was apparently longer than the receiver aerial.

Mr. Gheury.

Mr. M. E. J. GHEURY (*communicated*): On page 330, it is stated that the earthing gave some trouble. I think that the accepted idea is that shape is more important than area, the shape giving the greatest electrostatic capacity being the best possible. This, for a given area of netting, would not be circular or square pieces, but rather long strips placed in star formation, the aerial being connected to the centre of the "star." This is in agreement with theory, the electrical conductivity of such an earthing device being proportional to its electrostatic capacity. Yet, what was practically a star with two branches has not given satisfaction. It was, however, better than other connections tried. The laying of wire netting on the ground, simply, would, in any case, give an inferior earthing, judging by the trouble taken when establishing a station to have the earthing plates imbedded in the soil, deeply enough to be in close contact with moist earth, but of course this could not be used with a movable station.

The effect of rain upon the transmitting current is peculiar, being opposite to what one would expect. Was the effect the same on the current in the receiving circuit?

I have spent much time on the measurement of wave lengths for wireless telegraphy work, and found that the existence of wandering capacities, such as people, in the neighbourhood of the instrument was the cause of irregularities that cannot be overlooked in some kinds of experiments. These changes affect the tuning, the wave length increasing when several people are in the vicinity, and decreasing again to its former value when they are gone. The proximity of the operator himself affects the results, and to get values that can be compared to one another, he must keep in the same position. I ascertained, in a particular case, an increase of 7 per cent. in the wave length of a coil, due to the proximity of the hand to the coil. How far this source of error could be the cause of the "mysterious" irregularities mentioned I cannot tell, but I should like to have the author's opinion on this point, as it has interfered a great deal with the experiments I was doing last winter.

The President.

The PRESIDENT: I have not anything very serious to add to the discussion; but I would like just to refer to one point. The authors speak of making a good telegraphic earth by attaching the wires to the sheathing of a cable. I do not think they can ever have had much to do with submarine cables, otherwise they would know that it is not so easy to get a good telegraphic earth by that means. The sheathing has to be prepared properly, and it happens very often that it is covered

The President.

with tarred jute, which is a very good insulator. It is certain that the telegraphic earths are not often good earths, and I think that is also apparent from the authors' experiments.

Messrs. Duddell and Taylor.

Messrs. DUDDELL and TAYLOR (*in reply*): We wish to thank the speakers at the meeting, and all those who have sent contributions to the discussion, for the very kind way in which they have received our paper. Captain Jackson's remarks are most complimentary; he has had a very extended experience in practical wireless telegraphy in our Navy, and he finds that our results are in accord with his experience. Captain Jackson suggests that the pressure per square foot of the earth netting when rolled up on the ground was greater than when flat, so that the extra pressure made a better earth. We do not think that this affected our results, as the netting was pegged tight down to the ground at its ends when unrolled. That the aerial in the Bushy Park experiments was much too short to give the best results with the wave lengths used we regret; we should very much have liked to carry out tests with a 100 ft. aerial and 400 ft. wave, but it was impracticable. The Bushy Park tests were, as we state at the commencement of our paper, preliminary tests, and were made to see if the instruments would give reliable results, and it was owing to the satisfactory results obtained at Bushy Park that permission was obtained for the more extended experiments between the *Monarch* and Howth described at the meeting, and now added to the paper as an Appendix. When using the aerial considerably shorter than a quarter the wave length, as was done in the Bushy tests, we do not entirely agree with Captain Jackson that tuning "simply means lengthening the aerial wire and bringing the receiver to the position where the current is at the maximum." The tuning did increase the length of the air wire and did bring the measuring instrument slightly nearer the position of maximum current, but it also had the far greater effect of increasing the current in every point of the air wire.

As regards the humps on the product curves in the *Monarch* experiments, we have given an explanation in the Appendix which we think more nearly fits the results than the two-wave theory advanced by Captain Jackson.

The greater part of Dr. Sumpner's criticisms depended on whether in calculating the R.M.S. current during a single train of oscillations we should multiply the R.M.S. current during the train plus the interval by the simple ratio of the times, or by the square root of that ratio as we did in the paper. Dr. Sumpner admits in his communication that we were correct in multiplying by the square root; but still thinks that our estimate of the voltage induced in the air wire is too small: here we are inclined to agree with him, as we purposely made our estimate in the most conservative manner to make our case the stronger, that the instantaneous voltage induced in the receiver air wire is really quite high.

Mr. Pochin contributes some very interesting remarks on earth connections, and raises the important question of coupling. That the improved transmission with the weaker coupling was due to the sharper tuning with the purer wave is no doubt correct; but the

simple explanation that the purer wave was produced because the two paths from the air wire to earth have equal impedance is not sufficient to cover all the known effects. For instance, the advantage of weak coupling is as great when the closed oscillating circuit and the aerial are connected by mutual induction so that there is only one path from the aerial to the earth. **Messrs. Duddell and Taylor.**

The results described in the Appendix obtained by varying the coupling must not be taken as showing all that can be achieved in this direction, as they were made only to find the best point of attachment of the aerial for these special tests. When a closed oscillating circuit is associated with the receiver air wire, still sharper tuning is obtained and the effect of the coupling accentuated.

Dr. Fleming criticises our not having given the actual capacity of our jars and the self-induction of our coils, and then proceeds to explain the reasons why the measurements of these quantities should be made under the actual conditions of working. We quite agree with Dr. Fleming as to the value of such data, but we unfortunately had no means at our disposal for making the tests *under working conditions*, and we did not wish to give misleading values obtained in the ordinary way at lower frequencies. We venture to think, moreover, that authorities are not yet quite agreed as to whether such measurements as have yet been made in this direction can be safely assumed to be accurate for the high frequencies involved in wireless telegraphy. As to the method of calculating the wave lengths employed in our paper, we thought that we had made it clear on p. 342 that we regarded the method only as "sufficiently accurate for a rough approximation." Dr. Fleming has devised a most ingenious instrument for measuring these wave lengths, and has no doubt had the opportunity of making tests on large practical installations as to how much the actual wave length differs from four times the length of the air wire. It is to be regretted that he gives no indication of the results of any of his own tests, but confines himself to quoting some one else's tests of the simple linear Hertz oscillator.

In the *Monarch* Howth tests, which possibly Mr. Gheury did not hear described, the star arrangement of the earth netting gave good results. Our tests, so far, indicate that the netting on the ground is the best form of wireless telegraphy earth. The effects produced at the transmitter and the receiver by rain were similar. No trouble with the capacity of the body of the experimenter affecting the readings was observed in the actual tests. In small scale experiments in the laboratory great trouble has been found from this effect, and the matter was referred to and shown experimentally at the meeting.

The President mentions the difficulty of making an earth to the sheathing of cables. In the *Monarch* Howth tests the cables had their sheathings prepared and a proper telegraphic earth made to them.

The President. The PRESIDENT: It is with much pleasure that I now ask you to give a very cordial vote of thanks to the authors. As regards the paper generally, I can only say that papers such as this are a credit to the Institution.

The vote was carried with acclamation.

MANCHESTER LOCAL SECTION.

LOW TENSION THERMAL CUT-OUTS.

By ALFRED SCHWARTZ, Member, and W. H. N. JAMES, Associate.

(*Paper read March* 14, 1905.)

The Thermal Cut-out or fuse is essentially a protective device, its function being to guard the circuits and apparatus connected therewith from injury due to abnormally large currents.

An excess current in a circuit may occasion injury in two ways by setting up—

1. Excessive heating.
2. Mechanical or electrical strains and effects, either in the conductors themselves or in the apparatus connected to them.

In the first case the time duration of the excessive current directly affects the resulting injury, whereas in the second case the damage done may be practically instantaneous.

All electrical apparatus should be capable of carrying continuously its normal current without injury, and also of carrying currents very considerably in excess of this for short intervals of time.

The requirements for an efficient protective device would, therefore, seem to be—

1. Safe operation with a definite excess current within a given time, at the voltage of the circuit on which it is employed.
2. Efficient operation with currents largely in excess of that required to bring it into action.
3. Suppression of the arc consequent on rupture without explosion or damage to neighbouring parts or connections.
4. Reliability of action.
5. Ease of replacement and inspection.
6. Non-interchangeability of devices of different ranges.
7. Simplicity of construction.
8. Low first cost, and cheap renewal of wire.

In spite of the fact that a vast amount of opprobrium has been heaped upon the Thermal Cut-out, there seems to be no valid reason

why it should not, under proper conditions, fulfil the foregoing requirements.

Although fuses have for the last quarter of a century played so important a part in electrical engineering work, no paper dealing directly with them has been presented to this Institution since Cockburn's paper on safety fuses in 1887; it may, therefore, not be out of place to review very briefly their history and development.

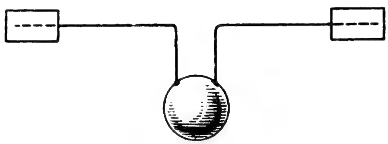


FIG. 1.

The fuse for the protection of electric light and power circuits is a development of the platinum wire cut-outs in use nearly half a century ago for the protection of submarine cables from the effects of atmospheric electricity.

Fuses of various kinds were in use as far back as 1874, and in 1879 Professor S. P. Thompson invented an "improved form of cut-out," shown in Fig. 1. This consisted of two iron wires connected by means

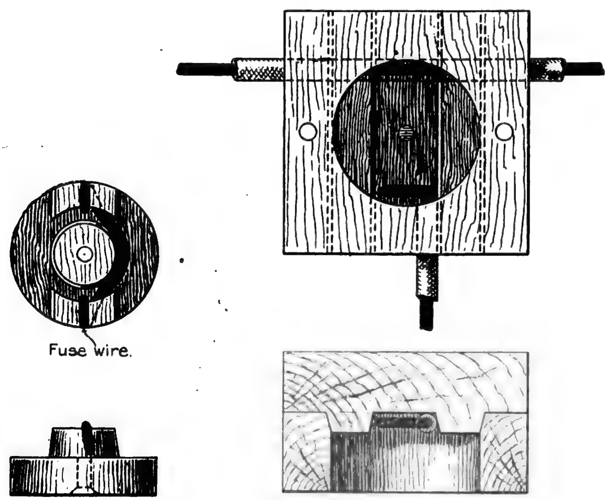


FIG. 2.

of a ball of lead, the wires and ball became heated, and the lead melted, allowing the wires to fly apart.

The earliest form of Edison plug fuse dates from 1880. A safety fuse with springs was the subject of a patent by C. V. Boys and H. H. Cunynghame early in 1883, and nearly a year later Lord Kelvin

produced a somewhat similar form. It consisted of two pieces of springy copper united by a soldering of fusible metal, which melted at a moderate temperature. Public attention was first directed to the danger of electrical fires by Mr. Musgrave Heaphy in a letter to the *Times* in 1883. The current opinion of electrical engineers was that fuses would introduce into the circuit a greater fire risk than that which they were intended to obviate, and as wood was the prevailing material in use for fuse blocks at that time, they were probably right. A fuse block belonging to this period is shown in Fig. 2, and the actual block removed from one of the most important public buildings in London some eight years ago is before you on the table.

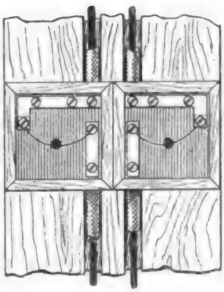


FIG 3.

In 1887 Cockburn brought out his well-known weighted fuse, Fig. 3, and the mica foil fuses of Killingworth Hedges were also used successfully.

The mounting of fuses on incombustible bases, and their grouping in accessible positions, has led up to the present distributing-board system.

Progress in America and on the Continent followed somewhat on the same lines; in the States, however, considerable attention has been paid to the development of enclosed fuses of the Mordey pattern with filled tubes; while in Germany the Edison plug type has been largely adhered to, from which the "Patrone," or cartridge pattern, has been evolved.

In this country low-tension Thermal Cut-outs have been developed in three distinct types, each with special features designed to meet the requirements of the service for which it is intended. In central station work and heavy current work generally the fuse has been displaced by the circuit breaker. The three types of circuit in which fuses are employed are given below, together with the general order of magnitude of the currents to be dealt with.

Type of Service.	Current strength per fuse.
1. Distributor boards	3 to 30 amperes
2. House service and switchboards ...	10 to 100 ,,
3. Motor services and section pillars on distributing mains	50 to 500 ,,

Before dealing in detail with the individual requirements of these types, it will be well to consider the behaviour of the wire itself when subjected to currents of fusing strength.

The current required to fuse a wire of circular cross-section of given material is dependent upon the following variables:—

1. Diameter.
2. Time of current flow.
3. Length of fuse wire employed.
4. Environment and position of fuse.
5. Previous history of fuse wire.

It will be seen from the foregoing that there may be an infinite number of fusing currents for any particular wire. The "normal fusing current" for a given wire, the length and environment of which are constant, may be defined as : The minimum current required to fuse the wire in such a time interval as shall be necessary for the wire to have attained its maximum steady temperature. The "normal carrying

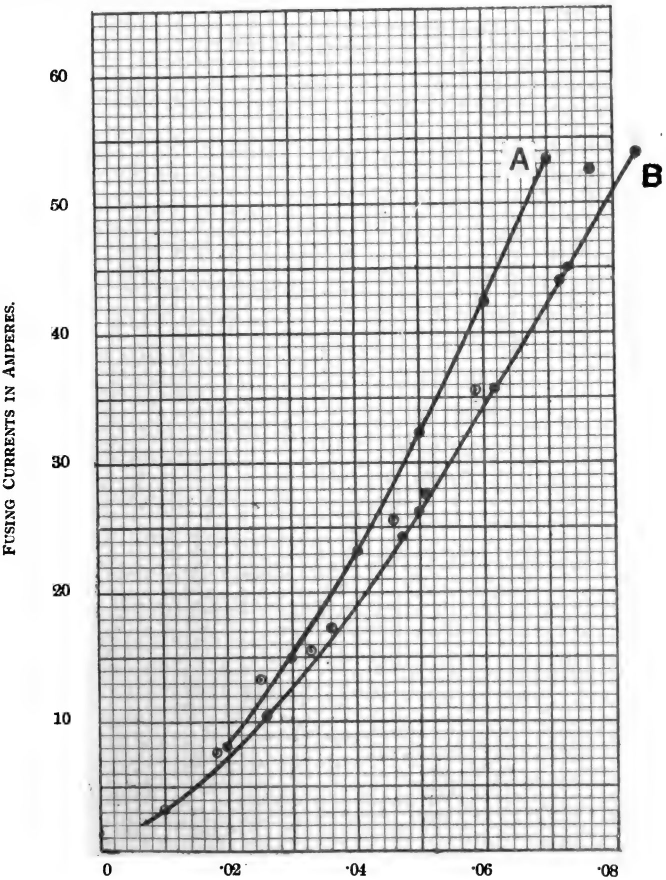


FIG. 4.—Curves connecting Fusing Current and Diameter for Copper Wires.
A. Calculated from Preece's Formula $C = 2887d^{1\cdot5}$.
B. Authors' Experimental Results for Copper and Tinned Copper.
Preece's experimental results for copper shown by points in circles.

capacity" or "rating" of a fuse wire may be defined as : The maximum current which the fuse is capable of carrying continuously without deterioration or undue heating. It should, in the authors' view, be taken as one half of the normal fusing current for tinned copper wires.

Relation between Fusing Current and Diameter.

The first series of experiments undertaken by the authors was for the purpose of determining whether a law of the character $C = Ad^b$ connecting the fusing current (C) and the diameter (d) was true over any considerable range. In these experiments commercial tinned copper wire, fusing with currents from 1 to 100 amperes, were

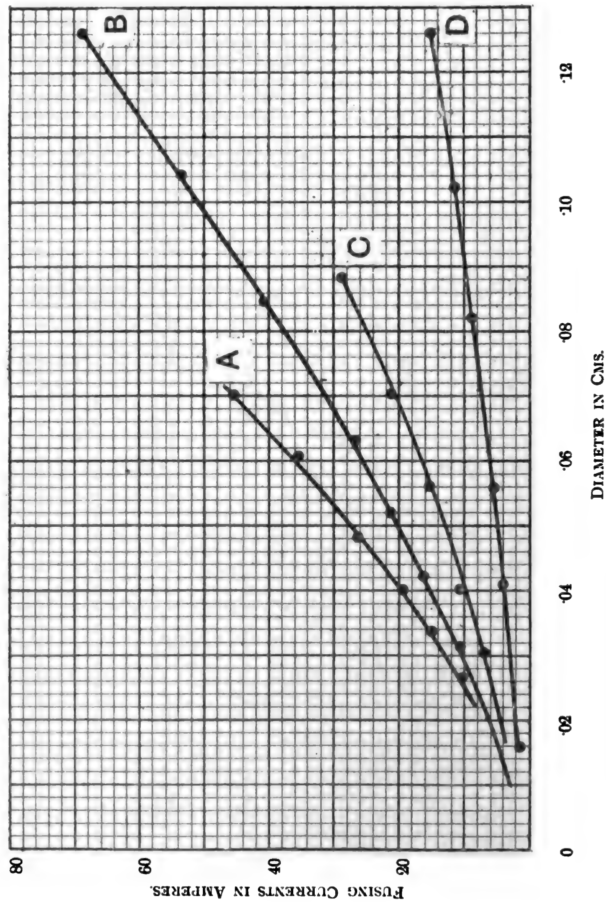


Fig. 5.—Curves connecting Fusing Current and Diameter.
A. Aluminium. C. Aluminium with Spring attachment.
B. Silver. D. Tin.

employed. The wires were supported horizontally, and were of such lengths that the fusing currents were independent of the cooling effect of the terminals. In each case the current was increased slowly, and the wire allowed to reach a steady temperature before rupture took place.

Curve A, Fig. 4, shows the relation between diameter and fusing current, plotted from Preece's formula $C = Ad^{\frac{3}{2}}$, while the circles mark

the actual points which he obtained by experiment. Preece's re-determination of the constant for copper in 1890 gives a curve which lies intermediate between A and B, and coincides very nearly with his experimental results. Curve B, Fig. 4, shows the authors' results for

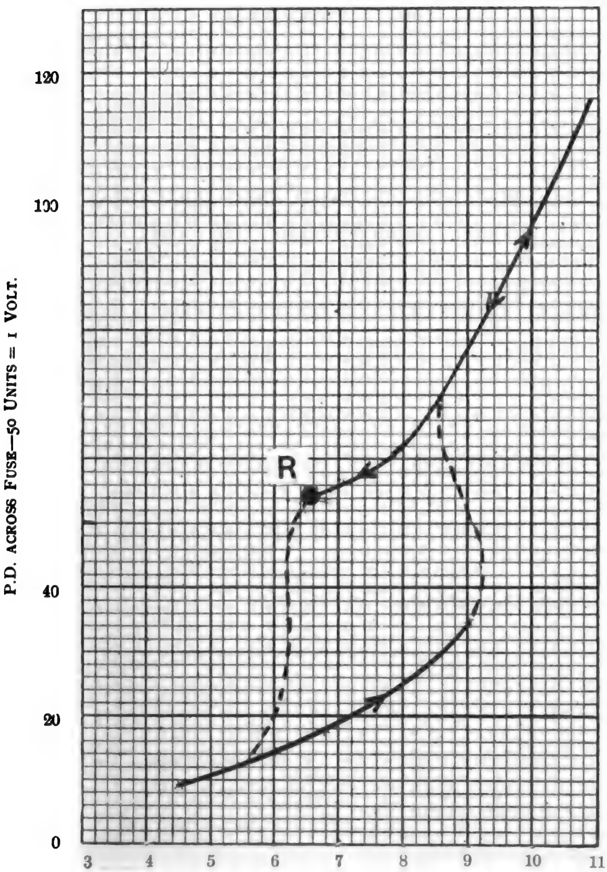


FIG. 6.—Curve showing the behaviour of an aluminium wire with a normal fusing current of 16·9 amperes, in which the current has been raised up to 11 amperes and then gradually reduced ; the wire rupturing at the point marked R as the current was being reduced.

tinned copper and pure copper. It is noticeable that the values for pure copper and tinned copper are practically coincident ; this is due to the small quantity of tin employed in the coating.

The curves in Fig. 5 show the relation between diameter and fusing current for wires of silver, tin, and aluminium. In common with wires

of lead and tin and their alloys, aluminium wires, particularly in the smaller diameters, are considerably affected as to their fusing current by the action of the atmosphere. A layer or skin of oxide or carbonate is formed of sufficient thickness and strength to hold up the metallic core of the wire when in a molten condition. Such wires break by the molten metal draining from the upper to the lower portion of the wire, the fusing current is consequently abnormal. This defect was noticed by Cockburn in connection with tin fuses, and he loaded his wires at the centre with a small lead ball to ensure prompt rupture. With aluminium wire this skin is particularly tough, and has a large effect upon the fusing current. This is shown in curves A and C, Fig. 5. Curve A is for aluminium wire, held in the ordinary way between terminals. Curve C shows the results obtained when the wire was placed under tension by means of a weak spring attached to one of the terminals. The same results may be obtained by making use of the repelling action of a magnet in place of the spring attachment.

If an aluminium wire, supported between terminals in the ordinary way, be subjected to a current sufficient to produce the fusion of the wire but not its rupture, and the current be then gradually reduced, the metal will remain molten even with quite a small percentage of the current originally necessary to produce fusion. This is due to the increased resistance offered by the molten metal and the greater quantity of heat produced in the fuse in consequence. As the resistance of the fuse compared with that of the whole circuit is negligible, the current flow will be the same in both cases. It is, in fact, rather a difficult matter to cause the metal to solidify again, as the fuse often ruptures as the current is being reduced. If, however, the metal solidifies without the rupture of the wire taking place, and the current be again raised to the point of fusion, the curve first obtained is nearly reproduced. The experimental results illustrating this point are shown graphically in Fig. 6.

In the case of fuses enclosed in tubes packed with sand, chalk, asbestos or other incombustible material, this effect is naturally intensified as the molten wire is closely supported on all sides, and special means have to be adopted to overcome the difficulty thus introduced.

Curves B, C, D, and E, Fig. 7, show the relation between Log. d (diameter) and Log. C (fusing current) for various metals, the spring attachment being used in the case of aluminium. Curve A shows the slope corresponding to Preece's Index of 1·5.

It is evident that this slope does not fit the curves of experimental results. An examination of the observed points on the curves B, C, D, and E, shows that a law of the order $C = Ad_b$ does not hold over the whole range. For small diameters the points lie above the line, while for the intermediate values they lie below the line, rising above the line again for the higher values.

Preece states that his law gives values for C which are too low for small diameters, but we find that his values are also too high for the larger diameters. Determining the law for tinned copper over a large

range (1 to 100 amperes), curve B, Fig. 7, the best values of A and b are contained in the formula

$$C = 1435d^{1 \cdot 327} \ (d \text{ in cms.}).$$

The above law gives somewhat low values for wires of large diameter. The current range from 1 to 100 amperes was therefore

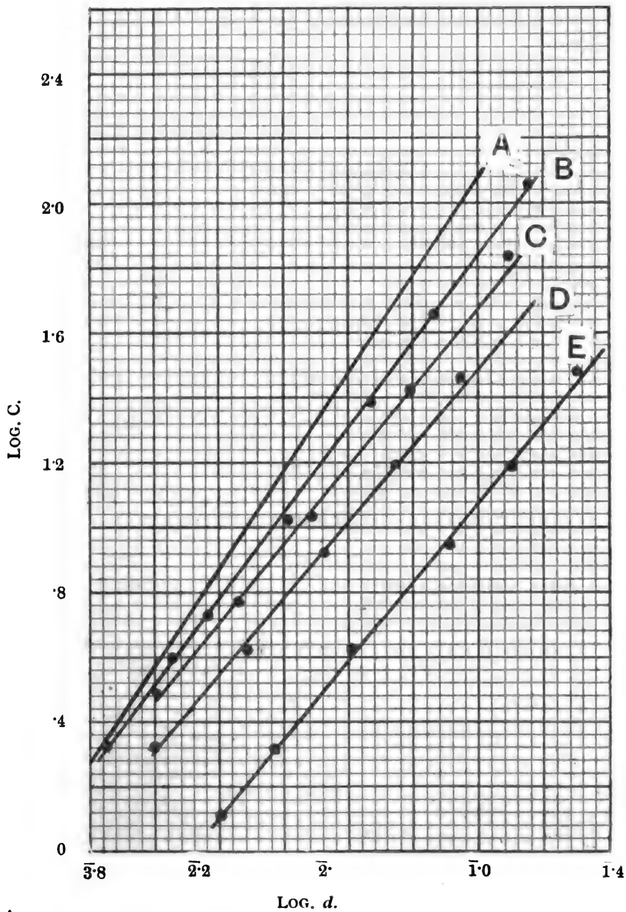


FIG. 7.—Curves showing relation between Log. d (diameter) and Log. C (fusing current).

A. Slope corresponding to Preece's Index, 1·5.
B. Copper.
C. Silver.
D. Aluminium (critical current).
E. Tin.

divided into two parts, 1 to 10 amperes and 10 to 100 amperes, and the best law found for each case, with the following results:—

$$\text{Range 1 to 10 amperes } C = 821{\cdot}3d^{1{\cdot}195}.$$
$$\text{,, 10 to 100 ,, } C = 1768d^{1{\cdot}403}.$$
$$d = \text{diameter of wire in centimetres.}$$

Tables I. and II. show the agreement between the values for the fusing currents for tinned copper wires of various diameters as calculated from the above laws, and the actual fusing currents for these wires as found by experiment.

TABLE I.

For tinned copper wires for fusing currents between 1 *and* 10 *amperes.*

Diam. in cms.	Fusing current calculated from $C = 821{\cdot}3d^{1{\cdot}195}$.	Observed fusing current.
·0049	1·43 amps.	1·5 amps.
·0117	4·04 ,, ...	4·0 ,,
·0151	5·48 ,, ...	5·5 ,,
·026	10·5 ,, ...	10·6 ,,

TABLE II.

For tinned copper wires with fusing currents between 10 *and* 100 *amperes.*

Diam. in cms	Fusing current calculated from $C = 1768d^{1{\cdot}403}$.	Observed fusing current.
·026	10·54 amps.	10·6
·0474	24·5 ,, ...	24·4
·0834	54·1 ,, ...	54·0
·144	116·5 ,, ...	115·0

It will be seen from these tables that the calculated and observed values are practically in agreement. For diameters in inches the law is expressed as follows for horizontal wires:—

$$\text{Range 1—10 amperes } C = 2501d^{1{\cdot}195}.$$
$$\text{,, 10—100 ,, } C = 6537d^{1{\cdot}403}.$$

The values of the index and constant necessary for use with various metals with the diameters in inches, centimetres and millimetres for wires in vertical or horizontal positions with large and small terminals, and for certain standard lengths, are given in tabular form in the Appendix.

For silver wires over the whole range given (1 to 70 amperes)

$$C = 3210d^{1{\cdot}287} \ (d \text{ in inches}).$$

It is again evident from the curve B, Fig. 5, that a law of the above form is not strictly true over the whole range, and if more accurate results are desired the curve must be subdivided.

For aluminium wires and fusing currents up to 50 amperes

$$C = 8539d^{1 \cdot 461} \text{ (}d\text{ in inches).}$$

This approximates to the index for aluminium obtained by Preece, but the circumstances are not quite normal, since at about 50 per cent. of

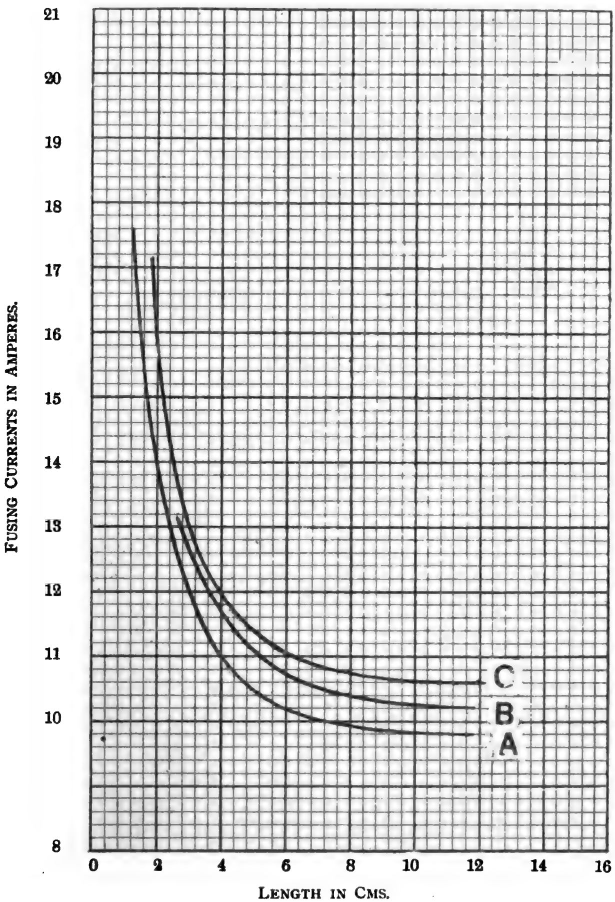


FIG. 8.—Curves showing effect of position on Fusing Current of a tinned copper wire No. 33 S.W.G., normal fusing current 10·6 amperes.
A. Vertical.
B. Inclined at 45°.
C. Horizontal.

the ultimate fusing current the metal becomes molten in the core of the wire, and rupture finally takes place as already pointed out, due to the draining of the metal to the lowest point of the fuse. The law connecting the diameter with the critical current for aluminium wires, that is

the current at which the metal becomes molten, is $C = 2091d^{1\cdot271}$ (d in inches).

For tin wires the law again does not hold over the whole range :—

$$\left.\begin{array}{llll}\text{Range} & 1\text{—}10 \text{ amperes} & C = 420\cdot6d^{1\cdot131} \\ \quad ,, & 10\text{—}80 \quad ,, & C = 819d^{1\cdot32}\end{array}\right\} d \text{ in inches.}$$

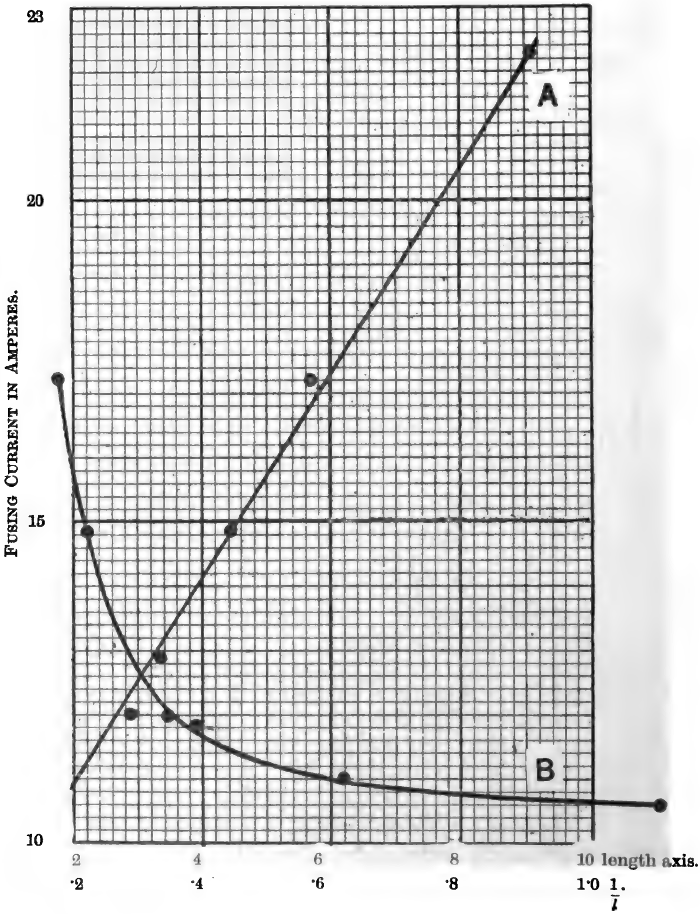


Fig. 9.—Curves for a Tinned Copper Wire, No. 33 S.W.G. horizontal.

Curve A shows the relation between $\frac{1}{l}$ and fusing current.

Curve B shows the relation between l and fusing current.

Effect of Position.

For copper wires the effect of being in a vertical position instead of a horizontal one is to decrease the fusing current by about 6 per cent.

for wires of small diameter with fusing currents up to 10 amperes. This is best expressed in the formula by keeping the index constant and altering the constant. For lengths of 1½ inches with small terminals

$$C = 3611d^{1.264} \ (d \text{ in inches}),$$

as against a constant = 3828 when horizontal.

For larger wires, with fusing currents, from 10 to 100 amperes, the decrease in fusing current when vertical instead of horizontal is about five per cent. with lengths of four inches and large terminals. The change in the constant is as follows:—

$$\left.\begin{array}{ll}\text{Vertical} & C = 12470d^{1.586} \\ \text{Horizontal} & C = 13100d^{1.586}\end{array}\right\} d \text{ in inches.}$$

Fig. 8 gives curves connecting fusing current and length for a tinned copper wire A vertical, B at 45°, C horizontal.

The effect of shortening the length of the fuse wire is to increase the index and the constant.

Tinned copper wires with fusing currents up to 10 amperes and small terminals in lengths of two inches and upwards have the same fusing current as for long lengths. For lengths below two inches the index and constant are increased as follows:—

Length.		
1½ in.	$C = 3611d^{1.264}$	d in inches. wires vertical. small terminals.
1 in.	$C = 5060d^{1.32}$	
1½ in.	$C = 5890d^{1.34}$	d in inches. wires vertical. large terminals.
1½ in.	$C = 3828d^{1.264}$	d in inches. wires horizontal. small terminals.
1 in.	$C = 5360d^{1.32}$	

Relation between Fusing Current and Length.

A number of experiments were made with tinned copper wires to determine the relation between fusing current (c) and length (l), and on plotting fusing currents as ordinates and $\frac{1}{l}$ as abscissæ, a straight line over a considerable range was obtained—see Fig. 9, curve A. This corresponds to a law of the form $C_l = M + \frac{N}{l}$, where M and N are constants depending on the diameter and "l" is the length of wire employed.

It was found that $M = P\,C_n$

and $N = Qd^2$;

where P and Q are constants for a given material with terminals of a definite mass and independent of the diameter of the wire.

C_n = normal fusing current for wires sufficiently long to be independent of the cooling effect of the terminals.

C_l = fusing current for a wire of length "l" cms.

d = diameter.

For tinned copper wires the experimental determinations of these

constants are shown in Table III., while for lead wire Grassot's* experimental results have been taken and collated in Table IV.

TABLE III.

Author's Experimental Values for Constants P *and* Q *for Tinned Copper Wires.*

d Diameter in cms.	M	N	C_n Amperes.	$P = \frac{M}{C_n}$	$Q = \frac{N}{d^2}$
·0049	1·31	0·52	1·5	·173	21,660
·007	1·87	0·94	2·1	·890	19,180
·0117	3·5	2·4	·0	·875	17,540
·0149	4·69	4·31	5·35	·876	19,410
·0151	4·53	4·52	5·5	·824	19,820
·0260	9·2	12·4	10·6	·868	18,340
·0474	20·3	43	24·4	·832	19,140
·062	31·5	65	36	·875	16,910

From the above table the mean values for tinned copper are as follows, $P = \cdot864$, $Q = 19{,}000$, so that the fusing current C_l for a length of "l" centimetres of tinned copper wire may be obtained from the formula—

$$C_l = \cdot864\, C_n + \frac{19{,}000\, d^2}{l}$$

C_n being the normal fusing current as previously defined.

TABLE IV.

Values of Constants P *and* Q *from Grassot's Experimental Results for Lead Wire.*

d Diameter in cms.	M	N	C_n Amperes.	$P = \frac{M}{C_n}$	$Q = \frac{N}{d^2}$
·05	3·23	5·55	4·0	·807	2,220
·055	3·74	6·92	4·6	·813	2,288
·07	5·97	9·07	7·0	·853	1,851
·085	7·22	14·56	8·9	·811	2,015
·09	7·74	16·52	9·9	·782	2,039

* Grassot, *l'Electricien*, vol. 10, p. 419, 1886.

From the above table the mean values of the constants for lead wire are as follows :—

$$P = \cdot 813. \qquad Q = 2083.$$

So that for lead—

$$C_l = \cdot 813\, C_n + \frac{2083\, d^2}{l}$$

l = length in cms.

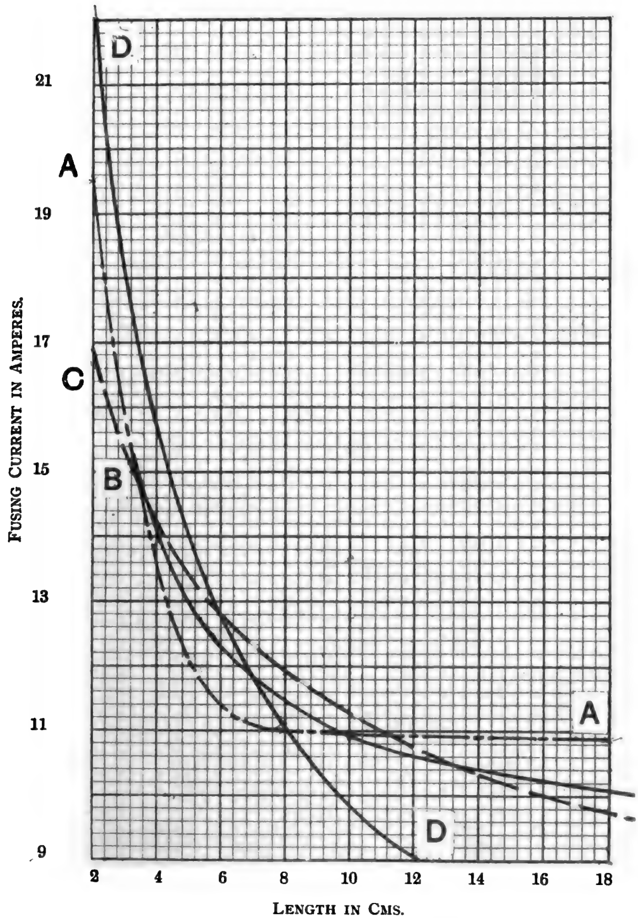


FIG. 10.—Curves showing the relation between Fusing Current and length for a lead wire 1 mm. diameter.

A. Grassot's Experimental Results.
B. Calculated from Authors' Formula.
C. " " Grassot's Formula.
D. " " Skrschinski's Formula.

It is a difficult matter to obtain an exact expression for the relationship between the fusing current and length of a wire. Skrschinski,* as the result of his experiments on lead wire of diameters from 0·62 to 1·55 mm. gives $C^2 l = K d^3$; Feldmann,† from considerations of the experimental results of Reinisch ‡ and Grassot,§ gives $C^2 \sqrt{l} = A d^3$.

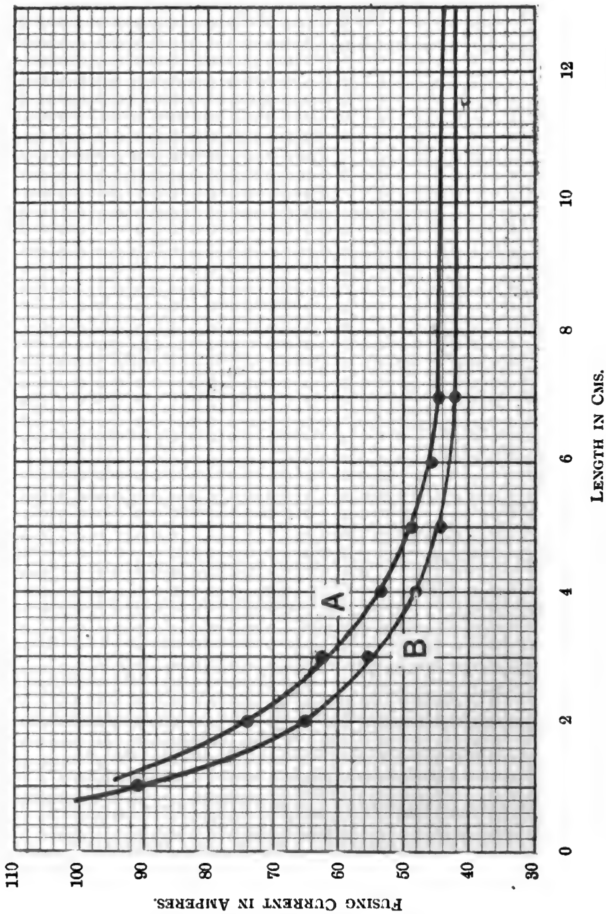


Fig. 11.—Curves showing the effect of mass of terminals on a lead wire, No. 13 S.W.G., with a normal fusing current for a length independent of the mass of the terminals of 42 amperes.

A. Large terminals weighing 870 grms. each.
B. Small terminals weighing 18 grms. each.

The mean values for the consonants of these investigators are as follows:—

Skrschinski $C^2 l = 9{\cdot}964\, d^3$
Grassot $C^2 \sqrt{l} = 1267\, d^3$
Reinisch $C^2 \sqrt{l} = 1906\, d^3$

* *No. 3 des Electritschestwo,* Dec. 14, 1890.
† Ueber Bleisicherung, *Electrotechnische Zeitschrift,* vol. 13, 1892.
‡ *Zeitschrift für Electrotechnik,* vol. 1, p. 243.
§ *l'Electricien,* vol. 10, p. 419, 1886.

Feldmann :—

(1) For terminals weighing 300 grms. $C^2 \sqrt{l} = 1350\, d^3$
(2) For terminals weighing 60 grms. $C^2 \sqrt{l} = 1000\, d^3$

Feldmann was the first to show the influence which the mass of the terminals has on the fusing current. In order to obtain a direct comparison between the results given by the authors' law $C = M + \frac{N}{l}$ and the laws $C^2 l = k\, d^3$ and $C^2 \sqrt{l} = A\, d^3$ enunciated by the above-named investigators, Grassot's experimental results have been taken as a basis. These experimental results are shown in Fig. 10, curve A; the calculated results from the authors' law are shown in curve B, from Skrschinski's law, curve D, and from Grassot's law, curve C. In the case of curve D, Skrschinski's constant was used; this holds true only for the terminals he employed. Their mass is not stated, but they were probably very heavy.

Effect of Terminals.

The effect of the length of wire employed and the mass of the terminals is much greater in the case of lead than in the case of copper, owing to the increased cross-sectional area required for a given current-carrying capacity. The radiating surface being directly proportional to "d," while the surface available for the conduction of heat along the wire is proportional to d^2.

Fig. 11 shows the cooling effects due to using terminals of different mass; curve A shows the relation between fusing current and length for a lead wire with a normal fusing of 42 amperes, the wire being supported horizontally and the mass of the terminals being 870 grms. each.

Curve B shows similar results with smaller terminals weighing 18 grms. each. For copper wires this effect is very much smaller; in fact, with copper wires with fusing currents up to 10 amperes and lengths of 2 inches and upwards it may be neglected.

Experiments with small terminals weighing 4 grms. taken from a commercial form of fuse-holder gave the following results :—

TABLE V.

Effect of Terminals of Clipholder for Distribution Board on Tinned Copper Wires. Wires, horizontal; length, 2 in.

Diameter in cms.	Fusing current for lengths independent of cooling effect of terminals.	Fusing current in commercial holder. Length, 2 in.
·0049	1·5	1·5
·007	2·1	2·15
·0117	4·0	4·02
·0151	5·5	5·47
·026	10·6	10·9

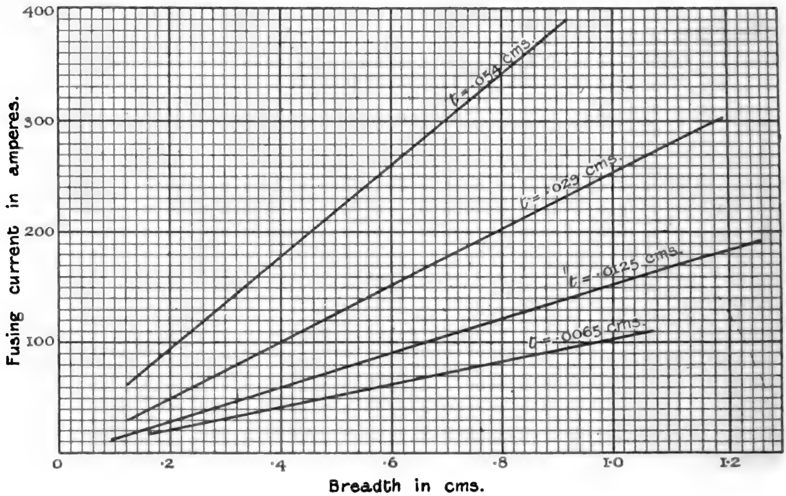


FIG. 12.—Curves connecting Fusing Current and breadth for copper strips of constant thickness *t*. Strips horizontal length 5½ inches. Terminals weighing 49 grms. each.

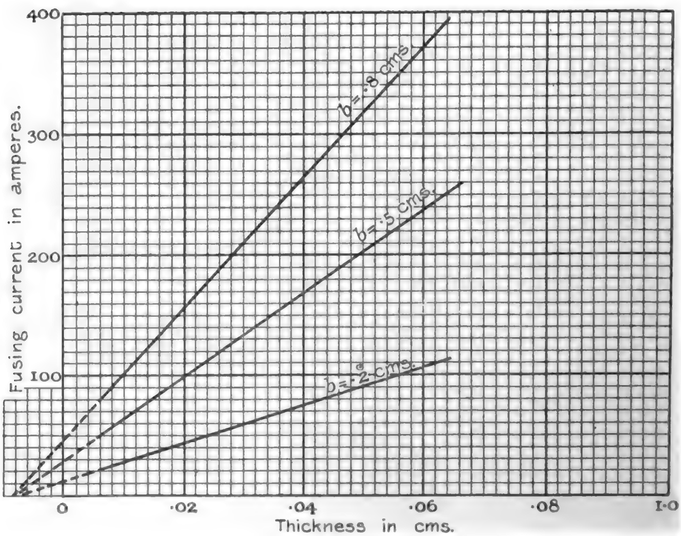


FIG. 13.—Curves connecting Fusing Current and thickness for copper strips of constant breadth; '*b*' strips horizontal length 5½ inches. Terminals weighing 49 grms.

The general form of the curves obtained from the authors' experiments on the effect of terminals of different mass is in agreement with the results obtained by Feldmann.

Copper Strip.

With copper strip the fusing current is proportional to the breadth with a constant thickness. The experimental results showing this are given in Fig. 12. It will be noticed that these curves practically all pass through the origin. If, however, we plot thickness against fusing current for strips of constant breadth, Fig. 13, we see that the curves pass through a point on the axis of thickness considerably to the left of the origin, this is probably due to the increased carrying capacity per unit area in the small strips owing to their relatively greater cooling surface. In Fig. 13 the full lines show the portions of the curves actually obtained by experiment, the dotted lines show these curves produced; the actual experimental curves if carried down to very low values, would pass through the origin.

It is probable that experiments with copper strip of greater thicknesses than those the authors have employed, would show that the relation between breadth and thickness was not represented over the whole range by a straight line, but by a curve.

A consideration of the curves in Figs. 12 and 13 shows that a law of the character

$$C = Ab\,(t + k) \text{ obtains;}$$

where C = fusing current,

b = breadth,

t = thickness.

With a length of $5\frac{1}{2}$ inches and the breadth and thickness in inches,

$$C = 40{,}550\,b\,(t + \cdot 00355).$$

In centimetre measure

$$C = 6{,}280\,b\,(t + \cdot 009).$$

The effect of length on the constant can be most easily expressed in the form of curves. Fig. 14 shows the relationship between the length in inches, and the constant "A" the constant "k" —which is necessary on account of the curves not passing through the origin as already mentioned—remaining constant. Curve A is for a vertical position, and curve B for a horizontal position of the strips. It will be noticed that the effect of position is more marked in the case of strips than in the case of wires. The decrease in fusing current due to a vertical position *vice* a horizontal position being about 10 per cent. for strips as against 6 per cent. for wires.

Table VI. shows the agreement between the observed fusing current for copper strip in a horizontal position and the values calculated from the authors' formula.

TABLE VI.

Observed Values for Fusing Current in Horizontal Copper Strips and Values calculated from the Authors' formula $C = 6920b\,(t + \cdot 009)$.

Thickness in cms.	Breadth in cms.	Calculated fusing current.	Observed fusing current.
·0055	0·8	80·2	78·8
·0065	0·4	42·8	42
·0125	0·3	44·6	46·8
·029	1·0	262·6	257
·054	0·6	261·2	260·5

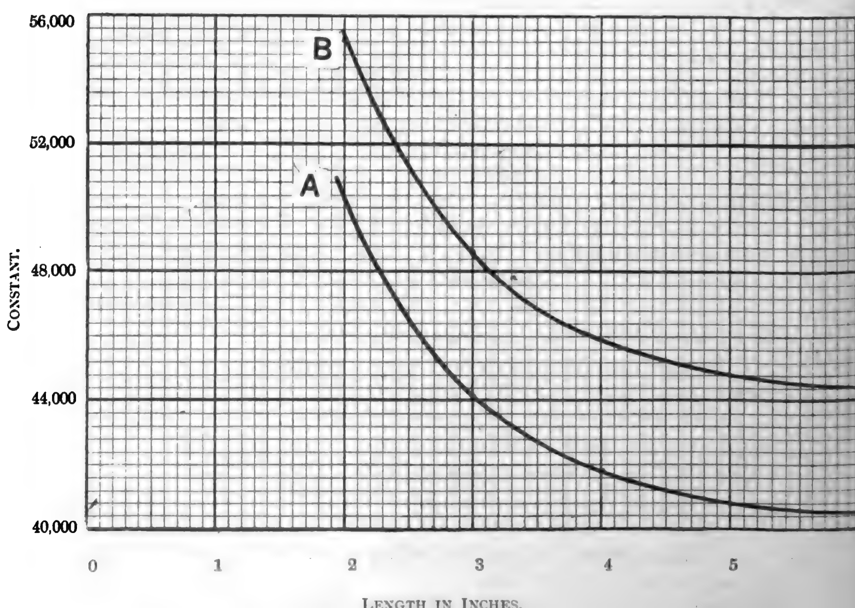


FIG 14.—Curves connecting the Constant "A" in the formula.

$C = Ab\,(t + k)$ for copper strip.
Curve A. Strip vertical.
Curve B. Strip horizontal.

Lead Strip.

The curves connecting fusing current and breadth for lead strip are similar in character to those given for copper, and are therefore not shown. There is this difference, however, that when extended backwards they do not pass through the origin, but cut the axis of breadth at a point to the left of it. This is due to the higher current density in the narrow strips. This effect is much more marked in the case of lead than in the case of copper. On plotting fusing current against thickness for a constant breadth, a straight line was not obtained; the curve, however, follows a logarithmic law—that is to say, with a constant breadth the fusing current is not proportioned to the thickness "t" but to t^n.

For lead strips $n = \cdot 74$.

The fusing current for vertical lead strips is given by the following equation:—

$$C = 2060\, t^{\cdot 74} (b + \cdot 016).$$

"b" and "t" in inches.

The ranges of experiments from which this law was deduced was as follows:—Thickness 0·0005 inch to 0·055 inch.
Breadth 0·08 inch to 0·4 inch.
Fusing currents 4 amperes to 100 amperes.

This formula can be relied on to within 3 per cent. with good commercial lead. An analysis of the sample used gave 99·8 per cent. of lead.

The agreement between the calculated and observed values for the fusing current of lead strip is shown in Table VIa.

TABLE VIa.

Observed Values for the Fusing Current of Vertical Lead Strip and Values calculated from the Authors' formula $C = 407 t^{\cdot 74} (b + \cdot 04)$.

Breadth in cms.	Thickness in cms.	Calculated fusing current.	Observed fusing current.
·46	·022	12·1	11·8
·96	·141	95·5	95·4
·75	·141	75·4	75·0

Effect of Enclosure in Tubes.

A series of experiments was carried out with a No. 33 S.W.G. tinned copper wire, free in air from terminal to terminal. The wire was placed along the axis of the tube, which extended the whole length of the wire, the ends of the tubes being left open. Tubes of glass and of brass were employed, with internal diameters varying from 0·4 to

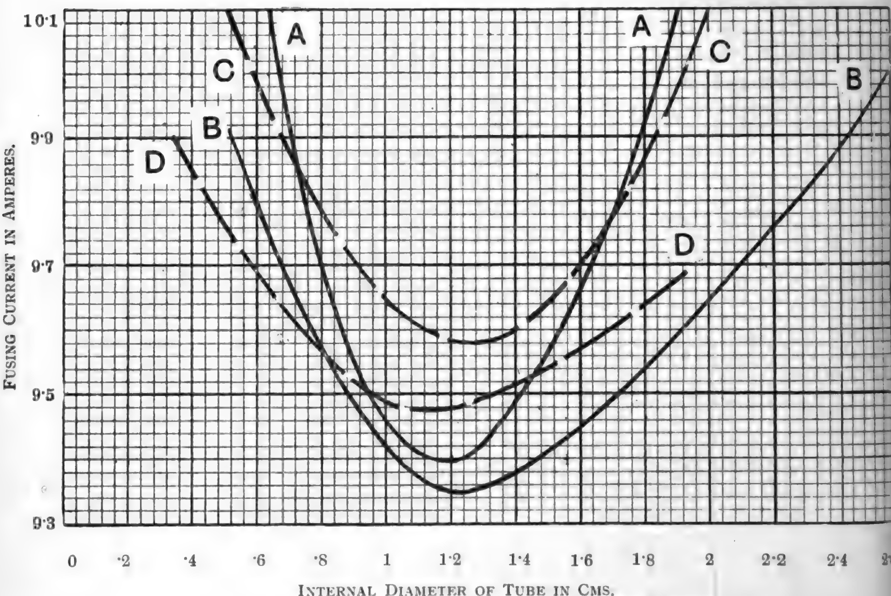


FIG. 14A.—Curves showing relation between the Fusing Current of a No. 33 S.W.G. tinned copper wire and the diameter of the tube enclosing it.

A. Brass tubes horizontal. C. Glass tubes horizontal.
B. Brass tubes vertical. D. Glass tubes vertical.

Wires placed along axis of tubes free from the sides; ends of tubes open. Normal fusing current of the wire in air 10·6 amperes.

2·6 cms., the tubes being arranged vertically and also horizontally. The effect on the fusing current of the wire is shown graphically in Fig. 14A. It will be noticed that in each case there is a certain size of tube for which the fusing current is a minimum, any departure from this size of tube with the size of wire employed producing an increase in the fusing current.

POWER LOSSES IN FUSES.

The power lost in a fuse wire of given length will depend upon :—

1. The normal fusing current; which depends, amongst other things, upon the melting point of the metal employed.
2. The strength of the current passing through the wire.
3. The specific resistance of the metal when cold.
4. The coefficient of increase of resistance with temperature.

The rate of increase of the power losses with an increased percentage of the fusing current depends to a large extent upon the last item. This is very noticeable in the case of copper.

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item. T.

In Fig. 15 curves are given for tinned copper wire showing the relation between the percentage of fusing current in the wire and the watts lost. It will be seen that up to 50 per cent. of the normal fusing current the losses are comparatively small, but that above this value the losses increase very rapidly. This is due to the large temperature coefficient of copper.

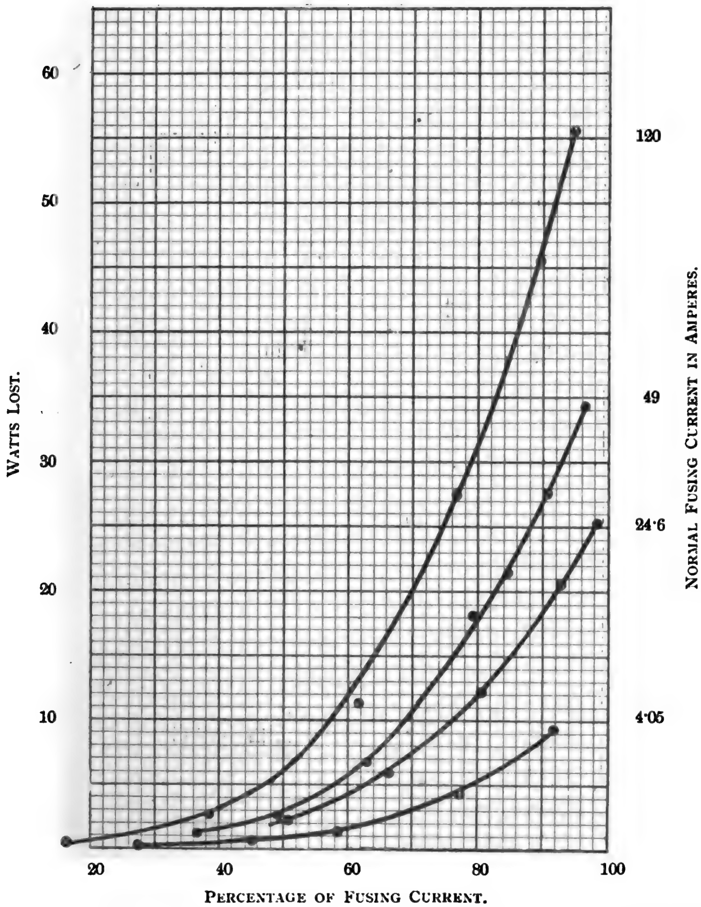

Fig. 15.—Curves showing relationship between watts lost and percentage fusing current for tinned copper wires of various diameters and a length of 8·5 cms.

Fig. 16 shows a similar set of curves for aluminium wires of different diameters. The inset on the curve at the point marked A is due to the sudden increase in resistance on the wire melting within its skin of oxide and the consequent diminution of the current, the voltage of the circuit in this case being low and kept constant. At

the points B and C this effect is absent, as the external resistance in the circuit was diminished in order to compensate and keep the current strength constant. In these experiments the wire was allowed to remain in a molten condition within the oxide film, and no spring attachment was used.

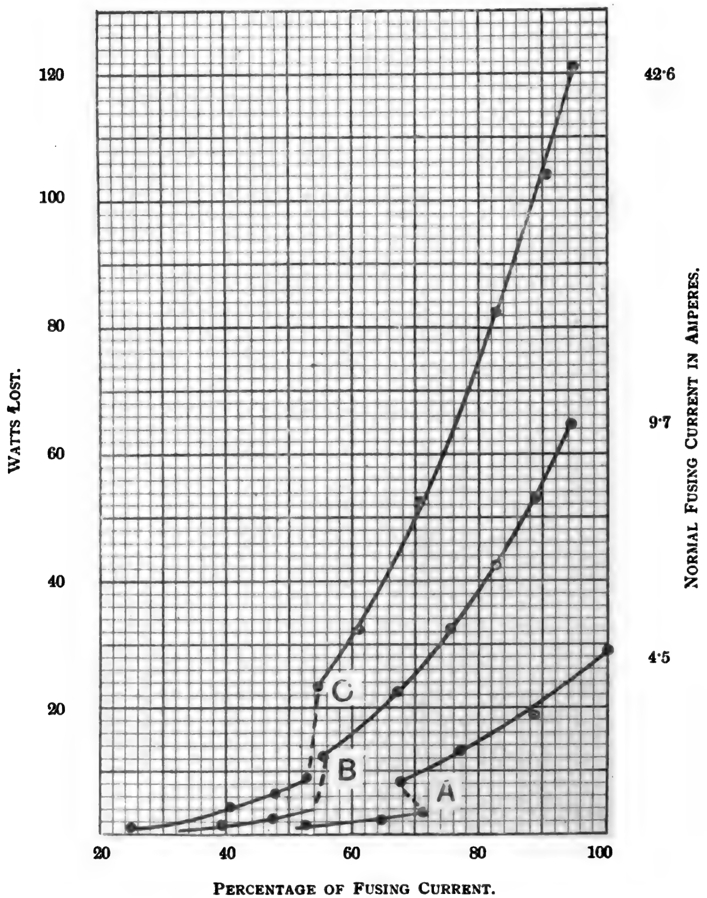

FIG. 16.—Curves showing relation between watts lost and percentage of fusing current for aluminium wires of various diameters with a length of 8·5 cms.

Fig. 17 shows the power lost in tin wires. The smaller wires behave much in the same way as aluminium wires as regards the oxide coating.

The wires of larger diameter seem to rupture when the metal becomes molten. The same effect has been observed in the case of

aluminium wires of large diameter; it is due to the film of oxide being unable to support the large mass of molten metal.

Fig. 18 shows a comparison between the power losses in wires of tinned copper, silver, aluminium, and tin under the same conditions. In these curves the fusing currents are plotted as abscissæ, and the watts lost at 90 per cent. of the fusing current as ordinates.

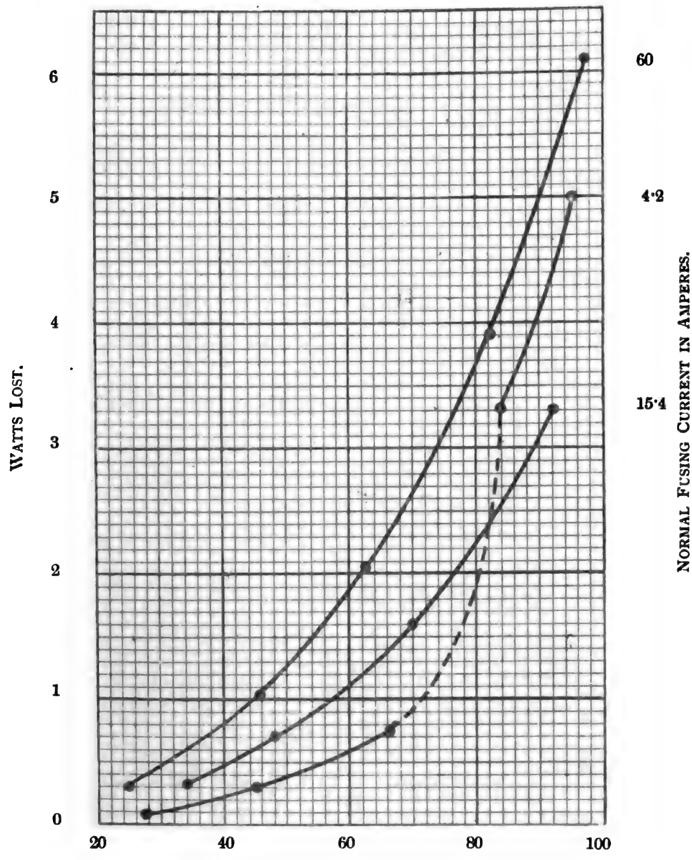

FIG. 17.—Curves showing the relation between watts lost and percentage of fusing current for tin wires of various diameters and a length of 8·5 cms. The dotted line shows the increase in resistance due to the wire fusing inside a skin of oxide.

Fig. 19 shows a similar set of curves, but in this case the ordinates represent the watts lost at 50 per cent. of the fusing current. In curves A and C the difference in the losses in aluminium wires with and without the spring attachment is very noticeable.

Tin is the most economical metal to use; then come silver, aluminium (with spring attachment), copper, and aluminium (without spring), in the order named.

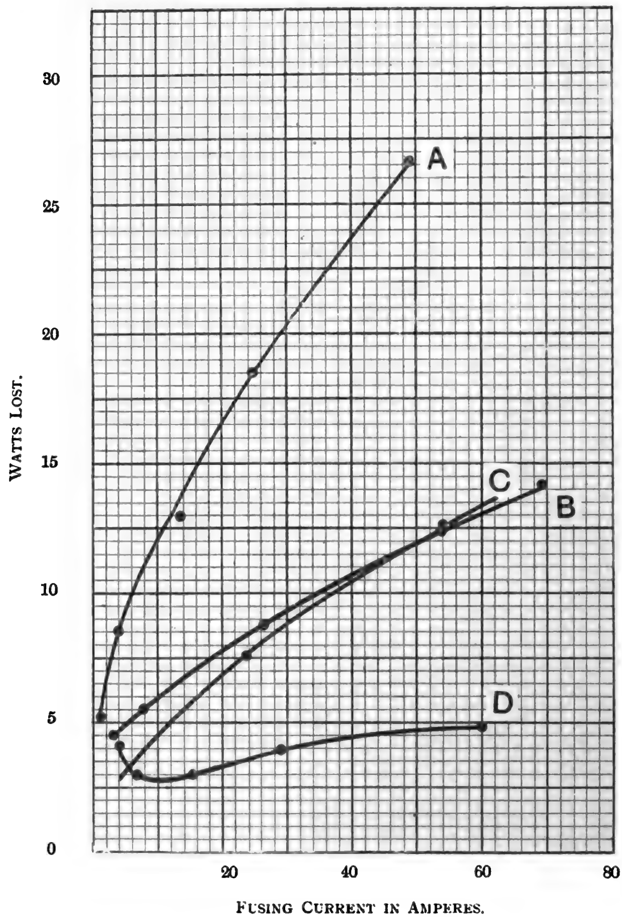

FIG. 18.—Curves showing the relation between the watts lost at 90 per cent. of the fusing current and fusing current for wires of different materials with a length of 8·5 cms.

A. Tinned Copper. C. Aluminium (with spring attachment).
B. Silver. D. Tin.

Having regard to the above results, it would seem desirable to run copper fuses at 50 per cent. of their *normal fusing current* rather than at a higher rate. The temperature attained under normal load will then be moderate, and oxidation will be slight. On the other hand, fuses rated to blow with an excess current of 50 per cent. of their

normal carrying capacity get far too hot, and oxidise to such an extent as to require frequent inspection and renewal.

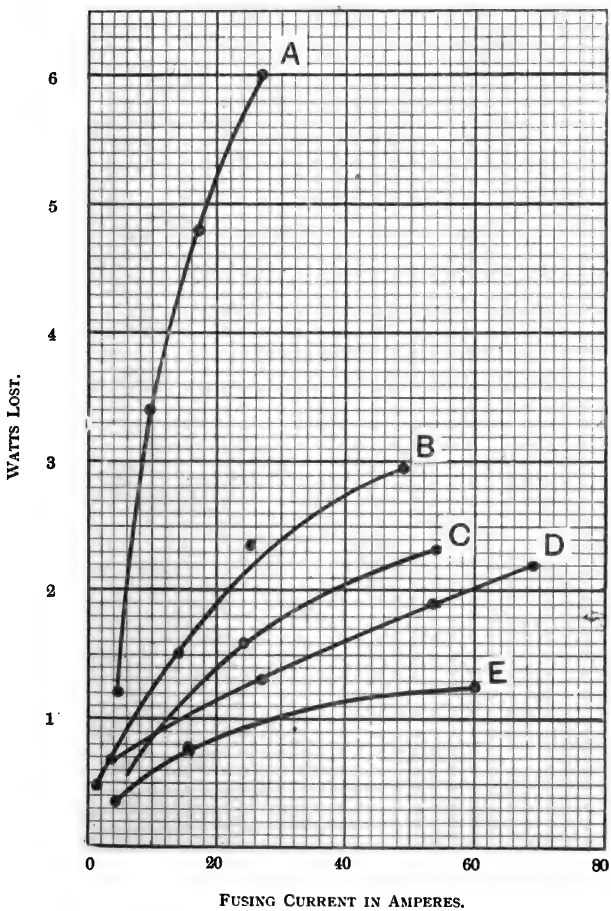

FIG. 19.—Curves showing the relation between the watts lost at 50 per cent. of the fusing current and fusing current for wires of different materials of length 8·5 cms.

A. Aluminium (no spring).
B. Tinned Copper.
C. Aluminium (with spring attachment).
D. Silver.
E. Tin.

Heim* has made a number of determinations of the drop in fuses in actual installation with the following results :—

* *Elektrische Beleuchtungsanlagen*, 1903, p. 319.

TABLE VII.

A.

Lead Fuses for 110 Volts complying with the Regulations of the German Institution of Electrical Engineers.

Normal carrying capacity in Amperes ...	30	60	100
Voltage drop per fuse	0·051	0·057	0·061

B.

Small Plug Fuses from the A.E.G. with Silver Wire for Pressures up to 250 Volts.

Normal carrying capacity in Amperes	0·5	1	2	4	6
Voltage drop per fuse ...	0·12	0·12	0·45	0·12	0·10

C.

Plug Fuses from the A.E.G. for 550 Volts with Silver Wire.

Normal carrying capacity in Amperes	2	4	6	15	20
Voltage drop per fuse ...	0·48	0·36	0·26	0·19	0·15

It will be noticed from this table that the voltage drop in these fuses increases with the pressure of the services for which they are intended. This is due to the increased length of fuse required to deal successfully with short circuits at the higher voltages.

The authors' experiments on copper fuses show that in general an average drop of 0·15 volt may be reckoned on per fuse way at full load. In an ordinary house installation we may assume that the current for any particular lamp will have to pass through three double-pole fuses on its journey from the supply company's mains to the lamp in question. The total pressure drop in the fuses will therefore be $3 \times 2 \times 0{\cdot}15 = 0{\cdot}90$ volt; a drop which should certainly not be neglected when considering the total drop in volts in the circuit. Fuses immersed in oil have a large drop in volts in them on account of the high current density at which they are run.

The pressure drop in a tinned copper wire immersed in oil at an initial temperature of 108° F. is given in Table VIII. The temperature of the oil is necessarily high under working conditions.

TABLE VIII.

Showing voltage drop and percentage of fusing current for a Tinned Copper Wire immersed in oil at 108° F. Normal fusing current of the wire in air 4 amperes and in oil 18 amperes. Length of wire, 3·3 inches.

Volts across Fuse.	Per cent. of Fusing Current.
0·58	18
1·14	29
1·80	39
2·50	49
3·60	65
4·67	78

The oil in such cases gets extremely hot, and in the authors opinion no cut-out in which the fuse wire itself is in contact with or immersed in oil before fusion has taken place should be permitted.

Overload Capacity.

The function of a fuse is to protect the whole of the circuit, including the conductors and the appliances connected to them. Many of these appliances require special consideration owing to their varying capacity for overload. Generally speaking, the capacity of the circuit for overload is considerably in excess of the overload capacity of the fuse which protects it; there are cases, however, which require special treatment. Arc lamps, for instance, are difficult to deal with, as they require a fuse which will stand the large current consequent on starting and the simular current rushes due to the sticking of the mechanism and other causes. On the other hand, if the fuses are set to blow with a hundred per cent. excess over the normal working current, the lamps may easily be burned out with a far less overload than this if it be continued for some time. It is difficult to see how the fuse can be set for a lower limit than that stated above without giving trouble, due to frequent blowing. The remedy seems to lie in careful and frequent inspection of the lamps. With regard to motors, the matter is somewhat simpler; the fuse should be set for 100 per cent. excess over the normal working full-load current; it will then be able to stand the variations in current likely to occur and to protect the leads from overheating. For the protection of the motor from severe overload, the overload release on the starter must be relied upon. It would be an advantage if these releases could be adjusted, and then closed or secured so as to be safe from the attentions of unauthorised persons.

Fig. 20 shows the relation between the percentage overload and the

time taken to fuse the wire from a cold state for tinned copper wires with normal fusing currents varying from 5 to 54 amperes and a length of 4½ inches. These curves are for moderate overloads—the maximum being 100 per cent.—the overload in each case being taken as the current in excess of the normal fusing current and expressed as a percentage of the latter.

Fig. 21 gives a comparison between the overload capacity of wires of silver, copper, aluminium, and tin, the normal fusing current of each wire being of about the same value—namely, 10 amperes. The curves

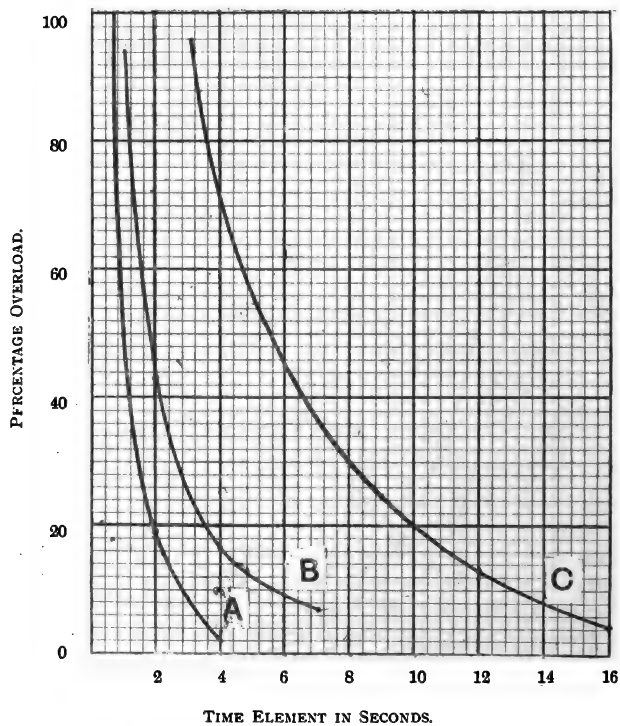

FIG. 20.—Moderate overloads on tinned copper wires, the overload being taken as excess over the normal fusing current.
A. Normal fusing current of wire 5·45 amps., No. 38 S.W.G.
B. " " " " 10·6 amps., No. 33 S.W.G.
C. " " " " 54·0 amps., No. 21 S.W.G.

show the relation between the time in seconds and the percentage overload. It will be noticed that tin is the most sluggish, and copper and silver are the quickest in action—the two latter being practically equal.

Fig. 22 shows the effect of excessive overloads—up to 2,000 per cent. —on tin wires. The times were taken on a chronograph drum driven

at constant speed by a motor. The higher values for the currents were obtained by substituting for the fuse a wire of equal resistance but of greater carrying capacity and adjusting the current to the desired value

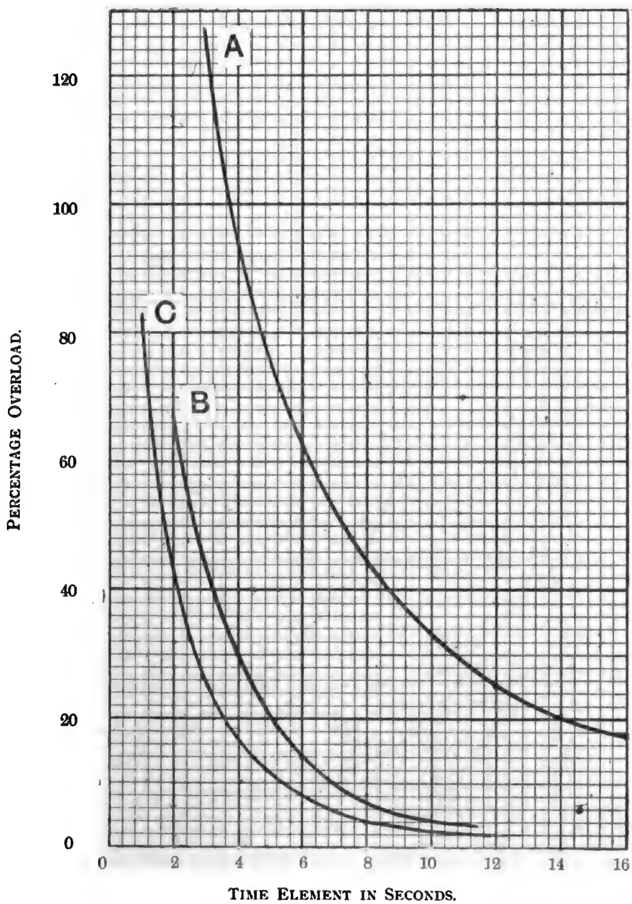

FIG. 21.—Curves showing the behaviour of wires of various materials on moderate overloads. The overload being taken as excess over the normal fusing current.

A. Tin.
B. Aluminium, with spring attachment.
C. Copper and Silver.

Normal Fusing Current for each wire about 10 amperes.

by means of a resistance, and then reinstating the fuse. It cannot therefore be stated definitely that the current ever reached this maximum value. It will be seen that the time for fusion decreases as the overload is increased. This result is borne out by Oelschläger's

experiments with the oscillograph subsequently referred to, although it is at variance with the conclusions of Stine,* who stated that the time of fusion tended to become constant with overloads above a certain value. As, however, his experiments were not carried out with overloads greater than 300 per cent., his deductions are hardly conclusive.

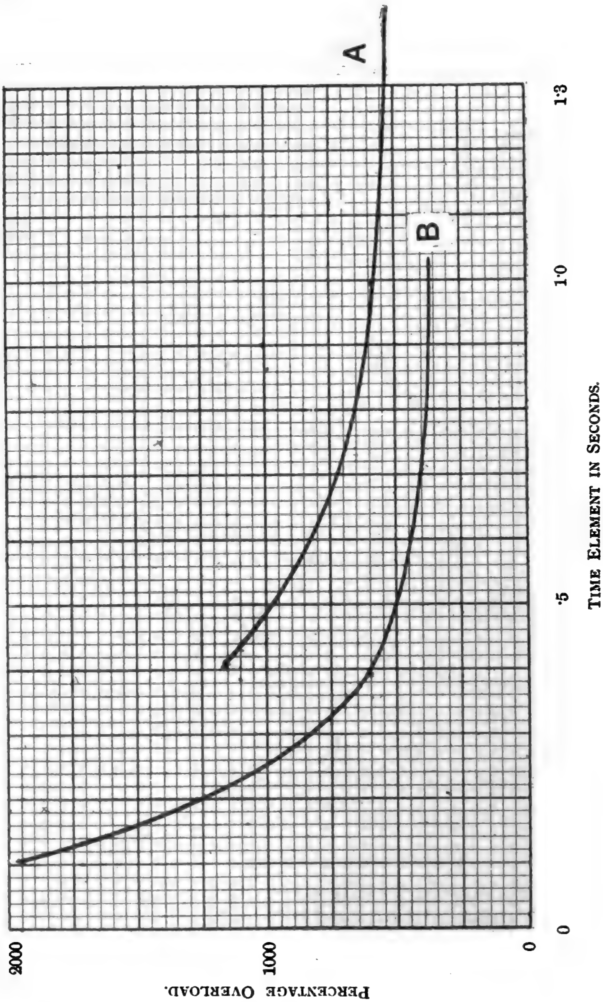

FIG. 22.—Excessive overloads on Tin Wires. The overload being taken as excess over the normal fusing current.

A. Normal fusing current of wire, 44 amps., No. 16 S.W.G.
B. Normal fusing current of wire, 21 amps., No. 12 S.W.G.

EFFECT OF WIRES IN PARALLEL.

Experiments were made with a tinned copper wire No. 22 S.W.G. diam. 0·074 cms. with a normal fusing current of 49·8 amperes. The wires were arranged in parallel, horizontally ¼ in. apart. The results are given in the following table :—

* Stine, Gaytes, & Freeman, *Trans. Amer. Inst. Elect. Eng.*, vol. 12, page 654, 1895.

TABLE IX.

Tinned Copper Wires in Parallel.

Number of Wires.	Fusing Currrent Amperes.	Fusing Current per Wire Amperes.
1	49·8	49·8
2	90	45
3	130	43·3
4	170·5	42·6
5	218	43·6
6	259	43·1

It will be seen that with three wires and upwards the current per wire is practically constant.

TABLE X.

Effect of Mechanical Injury on a Tinned Copper Wire, No. 33 S.W.G. of Length 3·4 in., and a Normal Fusing Current of 10·6 amperes. Wire horizontal.

Nature of Injury.	Fusing Current in Amperes.	Remarks.
Wire uninjured	10·6	Normal fusing current.
2·7 twists per inch	10·6	
5·5 " "	0·6	
10 " "	10·4	
33 " "	10	Volts across fuse, 1·6.
5 twists per inch put on and reversed. Repeated four times. Twists left on ...	10·2	Volts across fuse, 1·5.
12·5 twists per inch reversed and left off	10·5	
1·25 twists per inch put on and reversed 16 times, left off	10·2	
One kink at centre	10·5	Fused at kink.
Kink half-way between middle and one end of wire	10·6	Fused at centre and not at kink.
Blow near centre	10·6	Did not fuse where flattened by blow.
Two blows, one at each side of centre	10·5	Fused between indentations.
Five blows	10	Fused between indentations.
Wire cut half through ...	10·4	Did not fuse at cut.
Cut round wire	10·5	
1 loop...	10·2	Fused almost invariably where the wires crossed at the bottom of the loop.

Effect of Mechanical Injury.

Experiments were made to determine the effect of twists, cuts, kinks, and blows on fuse wires of copper and lead; the results are embodied in Tables X. and XI.

TABLE XI.

Effect of Mechanical Injury on a Lead Wire. Length 5 inches. Normal fusing current 35 amperes. Wire horizontal.

Nature of Injury.	Fusing Current in Amperes.	Remarks.
Wire uninjured	35	Normal fusing current.
3 twists in 5 inches left on...	35	No effect.
10 ditto ditto ...	35	No effect.
1 twist in 5 inches taken off, reversed and again taken off, repeated 6 times and left off	34·5	Note in all cases the twists were distinctly visible.
1 blow at centre flattened to half thickness	35	Fused at indentation.
2 blows, one at each side of centre	35	Fused between indentations.
6 blows	35	No effect.
2 cuts at each end half through wire	35	No effect.
Knife cut at centre	35	No effect.
1 kink...	34	

It will be seen from the above tables that the effect of mechanical injury is remarkably small, particularly in the case of lead wire. The same also applies to tin, the results for which are not given here.

Deterioration of Fuse Wires.

Fig. 23 shows the relative life of a tinned copper wire, No. 33 S.W.G., when run at various percentages of its normal fusing current. It will be seen that at percentages greater than 80, the deterioration is very rapid; it is interesting in this connection to note that copper wires attain a red heat with about 75 per cent. of their normal fusing current, and although oxidation commences at rather a lower temperature than this, it does not proceed rapidly unless red heat is attained. This severe oxidation at high overload will cause the fuse to act in a fairly short time if more than 60 per cent. in excess of the rated carrying capacity is used continuously.

Effect of Alternating Currents.

A careful series of experiments on the effect of alternating currents on fuse wires of various materials has been carried out by Jackson and

Ochsner* in the Engineering Laboratory of the University of Wisconsin. In their experiments, wires of iron, german silver, copper, and fusible alloys were placed in series for 550 hours on an alternating-current circuit of 110 volts and 125 frequency with 60 per cent. of their

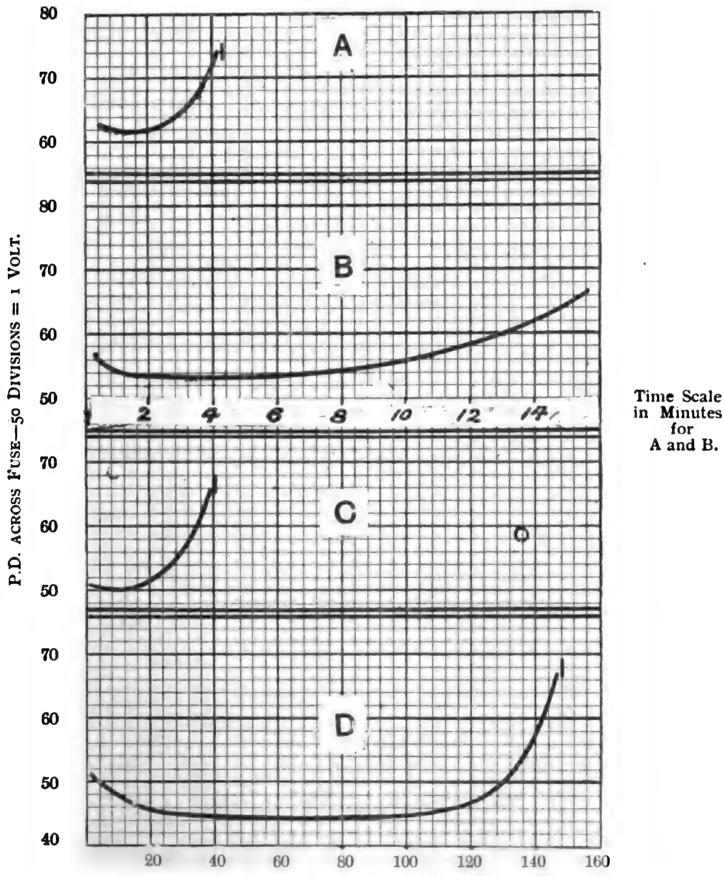

FIG. 23.—Curves showing deterioration of a Tinned Copper Wire, No. 33 S.W.G. Wires horizontal. Normal fusing current 10·6 amperes.

Curve A. Current = 94·5 per cent. of normal fusing current.
" B. " = 89·5 " " " "
" C. " = 84 " " " "
" D. " = 80 " " " "

rated current passing continuously. Careful determinations of their resistances were made at regular intervals, but disclosed no appreciable rise within the time named. Of six samples tested for variation in

* "Alternating Currents and Fuses," *Trans. Amer. Inst. Elect. Eng.*, vol. 11, page 430, 1894.

fusing current after the 550 hours run against unused lengths of the same wires, four samples showed an average lowering of 1·18 per cent., and two a slight rise of 1·22 per cent.

Short Circuits.

Although a fuse may operate quite successfully with 100 per cent. excess current, it has in practice to face the severe conditions of a short circuit. That these conditions are severe is well known, but the magnitude and time duration of the current rush and the voltage rise on the rupture of the circuit are not so well known to most engineers. The term "short circuit" is a relative one; for instance, a wire which fuses normally with 40 amperes might be said by some to be short-circuited when a current of 250 amperes passed through it, whereas on a dead short the current through it would, under certain conditions, be between 800 and 1,000 amperes.

The behaviour of a fuse when short-circuited through a resistance which limits the current to an excess of 20 per cent. of the normal fusing current is very different from the effect observed with currents five or six times as large, and this again differs very considerably from the effect of a dead short circuit.

A tinned copper fuse melting with a current about 20 per cent. in excess of its normal fusing current exhibits a greater tendency to arc than when melting under a current of four or five times this strength. This is due to the fact that with a small overload the wire will fuse first over a short length at its centre, and an arc will be formed across this small gap. This gap will increase as the ends of the wires are burned back, until the arc finally fails. With a large overload the heating of the entire wire is so rapid that fusion takes place along its whole length, and the wire is completely disrupted from terminal to terminal. Mr. H. A. Ratcliffe, of the Testing Department of the Manchester Corporation Electricity Works, who has had a large experience of fuse testing, has found that numbers of fuse fittings, which have successfully withstood a so-called short-circuit test with a current limited to seven or eight times the normal fusing current, were entirely destroyed on a direct short circuit. The fuse wire employed in these cases was tin, which, on fusing, is far more favourable to the formation of an arc than is copper. He has also found that on short-circuiting a 50-ampere fuse with an 800-ampere circuit-breaker in the circuit, that the breaker has been opened. That very large currents do pass under short-circuit conditions may easily be shown by short-circuiting a large fuse through a small one in series with it. In this way the authors have fused five copper wires in parallel, fed through a single wire of the same diameter, length, and material, the single wire, of course, fusing as well as the others. The powerfully destructive effects of the true short circuit are due in the first place to the large current which passes, which is limited only by the self-induction and resistance of the circuit. Where the fuse is directly connected to supply mains fed by a number of generators of large capacity in parallel, the resistance of the circuit will be extremely small, and the

current rush proportionately large. Secondly, the inductive voltage rise, due to the breaking of this large current in a small fraction of a second, is very considerable, and materially affects the formation of an arc. Oelschläger * has recently measured, by means of the oscillograph, the current, pressure rise, and time of fusion on short circuit in a Siemens-Schuckert cartridge fuse with a normal fusing current of 40 amperes. His results are as follows :—Fig. 24, curve A. shows the effect of limiting the fusing current to 180 amperes by means of a resistance. The circuit voltage was 110 continuous current, the limiting resistance 0·6 ohm, and the inductance 2·5 henry. Capacity of generators 1,000 k.w. at 110 volts.

An examination of this curve shows that from the time of closing the switch the current increased gradually, reaching the maximum value to

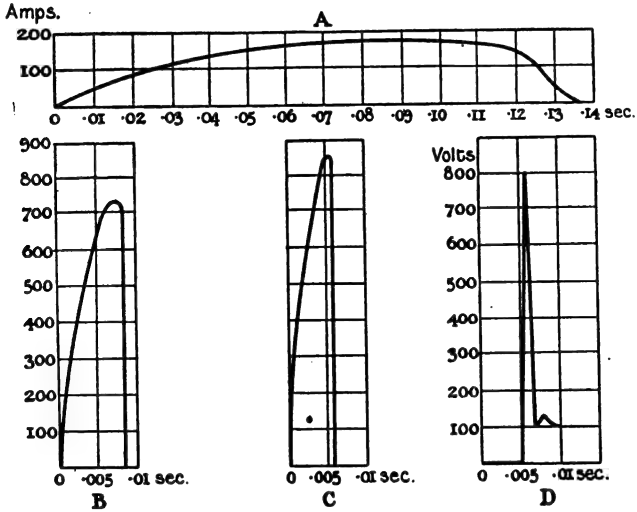

FIG. 24.

which it was limited by the resistance in 0·08 sec.; it then remained constant for 0·04 sec.; while the time in which the actual rupture took place was 0·02 sec. Further experiments were made with diminished resistance, and self-induction curve B shows the effect with a resistance of 0·01 ohm in series, and no artificial self-induction in the circuit. Curve C shows the magnitude of the current rush on direct short circuit, the artificial resistance being removed. As the resistance of the external circuit becomes smaller, the resistance of the fuse itself becomes relatively more important. The resistance of the fuse, which in this case was of silver, with a melting point in the neighbourhood of 1,000° C., was, when cold, 0·0054 ohm. The resistance of the fuse wire when hot was obtained by raising the current gradually to a point just short of the normal fusing current of the wire, and was found to

* *Elektrotechnische Zeitschrift*, vol. 25, 1904.

be 0·017 ohm. On a short circuit, with 110 volts neglecting the resistance of the leads, the maximum current would be $\frac{110}{0{\cdot}017} = 6{,}500$ amperes.

As a matter of fact, the current was found to be only 850 amperes. This is due to the natural self-induction of the circuit and the consequent relatively slow growth of the current, and also to the fact that fusion took place long before the current could reach its theoretical maximum value. The pressure rise, due to short circuit, is shown in Fig. 24, curve D. It will be noticed that at first the pressure across the fuse is practically nil, corresponding to the pressure loss due to a current of several hundred amperes in a resistance of 0·0054 ohm. Just before the melting of the wire the pressure rises to about 25 volts. At the moment of melting an enormous rise of pressure suddenly takes place, the total voltage being about 800, or nearly 700 volts above the pressure of the circuit. The actual breaking of the circuit took place in 0·00015 sec., the self-induction of the circuit being of the order of 10^{-4} henry.

After a small surge the pressure fell to 110 volts, the normal voltage of the circuit. In order to see whether the self-induction of the source of current (machines) had any effect upon the results, the experiments were repeated with a 110-volt battery giving 400 amperes. Curves of the same character were, however, obtained.

Connection between Normal Fusing Current and Length of Break.

It is frequently stated that there is no rational connection between the length of break or distance between the terminals of a fuse and the normal fusing current of the wire. It is a common practice, however, to increase the length of break with the normal carrying capacity of the wire, and this usage may be defended on the following grounds: On a short circuit, as has already been pointed out, the current is prevented from reaching the immense value to which it could theoretically attain by the fusion of the wire; it is evident, therefore, that the larger the wire employed, the greater the current will be before fusion takes place, and the inductive pressure rise, when the rupture of the circuit does take place, will be dependent upon the current passing at the time, and the time in which this current is broken. This inductive pressure rise will largely influence the formation of the arc, and the length of break must therefore be increased when large currents are to be broken on the fuse.

As the voltage of self-induction is dependent on the rate of decay of the current, it is possible that with large wires and open-type fuses this will be slower owing to the large mass of metal volatilised acting as a conducting bridge, and that in consequence the voltage rise will be less. Experiments on this point are in hand, but are unfortunately not yet completed. In the opinion of the authors the normal fusing current in copper fuses should not exceed 100 amperes per wire. Fuses for

larger currents should be made up of several wires in parallel, spaced about half an inch apart. Under these circumstances, although the mass of metal employed may be large, it does not seem probable that the time of decay of the current would be increased, provided, of course, that a proper length of break has been allowed. The double rôle which a fuse has to play in breaking the circuit with a predetermined current and suppressing the consequent arc undoubtedly militates against its reliability in the performance of the first function. The effectual suppression of the arc in some circumstances calls for the proximity of masses of cold material, such as porcelain or the passage of the wire through asbestos or other incombustible material. If the wire is in contact with any such bodies for a part or the whole of its length, its fusing current will be affected to a greater or less extent.

The authors find, however, for pressures up to 220 volts tinned copper wires in porcelain clip holders in which the wire is free in air for a length of 2½ inches between the terminals are quite satisfactory on a dead short circuit. For distribution boards the spacing should be rather more liberal than is at present customary, and the fuses should be screened from one another by septa of incombustible material to limit the spread of the molten metal. Wherever possible the contracts and terminals should be screened from the action of the arc.

Fuse Metals—Tin and Lead.

In the early forms of fuse, lead and lead alloy wires were used as they melted at low temperatures, and were therefore considered to be less likely to set fire to inflammable material in their immediate neighbourhood than wires of a metal with a higher melting point. It is, however, quite an easy matter, under suitable conditions, to raise wires of these metals to a temperature very much higher than that of their melting point—namely, to a bright red heat. A further disadvantage is that owing to their comparatively poor conductivity a larger mass of metal has to be employed to carry the normal working current than is required in the case of wires with a high conductivity, so that the mass of metal disrupted when fusion takes place is consequently much larger and the probability of the formation of an arc much increased.

The arc is much more persistent with these metals than with copper, so much so that fuse fittings that will stand a direct short circuit with copper wire may be destroyed when used with tin or alloy wires. This is probably due, as already pointed out, to the larger mass of these metals present and to a greater proportion of it being vaporised than in the case of copper. When a copper fuse is disrupted the greater part of the metal is scattered in the form of globules, and only a small quantity seems to be vaporised. The blowing of a copper fuse may be said to be "clean" compared with that of the metals under consideration, which is accompanied by a quantity of heavy fumes which are deposited on contiguous cold surfaces. These deposits are often difficult to remove, and certainly facilitate the formation of an arc

for fuses that are subsequently blown in the same holder. Although the metal pellets from the fusion of these metals are not so hot as the globules from a copper wire of the same carrying capacity, and they are, moreover, not scattered so far, yet the display of "fireworks" on a dead short circuit is considerably greater.

Further, these metals are soft, and although, as has been shown, the effects of mechanical injury are not as great as might have been expected, severe cutting may take place at the terminals unless the wires are soldered to copper or other suitable lugs.

The cooling effect of the terminals is also considerably greater in the case of lead and tin than of copper. In the case of alloys it is also difficult to secure the constancy of their composition as supplied commercially, and the alloys themselves are liable to change their structure, either due to the passage of the current through them or to the effect of repeated heating and cooling. These metals also become very brittle at a temperature slightly below their fusing point. The authors' experiments show that if they are subjected to vibration when in this state the fusing current is lowered by about three per cent. They are also liable to severe oxidation, with a consequent large increase of the current-carrying capacity of the wire under overload.

Silver

can be easily obtained of standard composition, is comparatively hard, of high conductivity, is not easily oxidised, and on fusion does not give rise to heavy vapours, and therefore does not encourage the formation of an arc. Against these advantages may be set its cost, and the fact that unless enclosed it is liable to have its surface converted into sulphide. Silver fuse wire is used very largely in plug and cartridge fuses for installation work in Germany, where Britannia metal is also employed.

Silver wires act more promptly than wires of lead or tin (see Fig. 21.

If a silver wire be placed in series with a lead wire of the same carrying capacity, in most cases the silver wire will be found to have opened the circuit cleanly and decisively, while the lead fuse has remained unmelted.*

Aluminium, Zinc, and Cadmium.

These metals possess valuable non-arcing properties, but require special arrangements, which are more or less troublesome; the two latter are also mechanically weak, and cannot be obtained in the form of wire.

Copper.

The authors strongly favour the use of tinned copper. It is easily obtainable of constant composition. It is mechanically strong, and the mass of metal required for a given carrying capacity is small,

* *Elektrotechnishe Zeitschrift*, vol. 19, page 591, 1898.

Care must be taken with the smaller sizes to see that the wire itself does not get into the thread of the terminal screws, otherwise it is easy to handle in sizes down to No. 38 S.W.G., which would be used to protect a three-ampere circuit. It does not oxidise perceptibly when carrying 50 per cent. of its normal fusing current, but at higher rates than this oxidation becomes troublesome. There is, however, no trouble from the holding up of the molten metal by the film of oxide. Unless guarded the molten particles may, on a dead short circuit, be scattered 15 or 20 feet, but this difficulty may be easily overcome by suitable protection. Considerable prejudice seems to exist against copper fuses on account of alleged increased fire risk. The risk of fire is threefold—First, owing to the wire becoming red hot prior to fusion; secondly, due to the scattering of the molten particles of metal; and, thirdly, owing to the formation of a persistent arc on fusion. With properly designed holders and fuse-boxes, in which all inflammable material is entirely excluded from the sphere of action of the wire, the fire risk from the first two causes is practically nil; while, as has been already pointed out, the risk from the third cause is less with copper than with more volatile metals.

Construction of Fuses.

The early forms of cut-out in which soft metals were employed were particularly prone to trouble at the contacts due to oxidation or the loosening of the contact owing to the different coefficients of expansion of the metals forming the terminals and the fuse wire. Soft wires are now generally soldered to copper or brass contact pieces.

It is very desirable that fuses should be easily removable for inspection and renewal, and be capable of being quickly replaced on a live circuit without shock or injury to the operator. This necessitates the fuse wire being mounted in a removable holder of insulating and incombustible material. Some of the various forms of contact in use between the fuse-holder and the circuit terminals are shown in Fig. 25.

Fuse-holders may be divided into three classes, according to the environment of the wire, as follows:—

1. Open type.
2. Semi-enclosed.
3. Enclosed.

In the open type the wire is free in air from terminal to terminal; in the semi-enclosed type the wire may be free in air for its whole length, but is surrounded by an incombustible and insulating tube of small or large diameter, or it may be passed for a small portion of its length—usually at its centre—through a hole or channel of small diameter in the porcelain holder or through a wad or washer of asbestos or other incombustible material. In the enclosed type the wire is enclosed in a tube or envelope of fibre or porcelain and packed

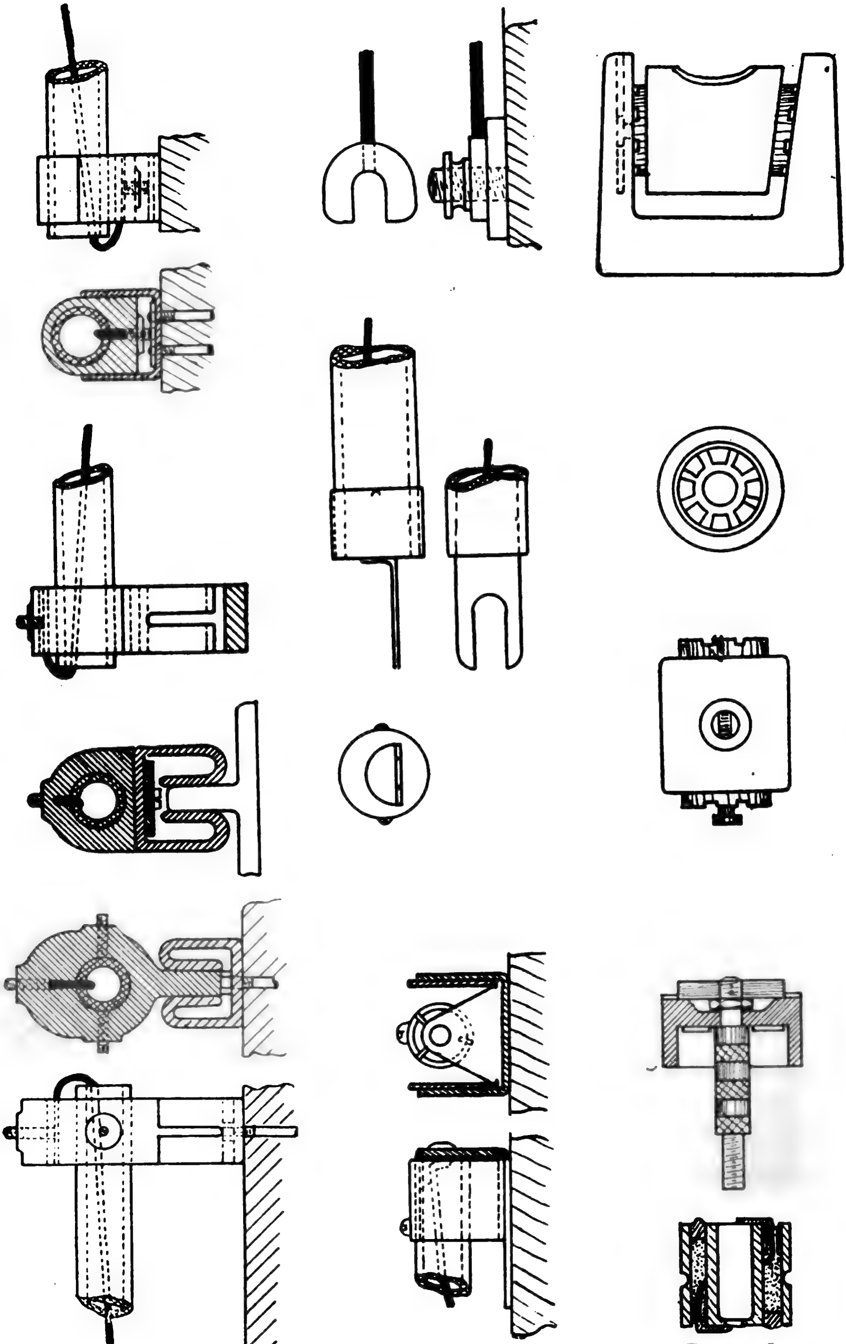

FIG. 25.

closely round with refractory insulating material. Whatever the environment of the fuse may be, it is desirable that it should be kept as constant as possible if the fusing current is to be in accordance with a pre-determined value. Where the wire is free in air its fusing current may be determined from the authors' formulæ, provided the limiting conditions are observed. Whenever the wire comes into contact with porcelain or other material its contact should be of a definite and constant character. The fusing current of the wire in the holder may then be determined by direct experiment. It must be borne in mind that fuse wires increase considerably in length before fusion takes place, and that in consequence they may sag or bend, and so come into contact with the holder. Where the enclosing tube is of vulcanised fibre a contact with the wire will lead to charring and possible firing on overloads.

Semi-Enclosed Fuses

should have the holders so constructed that any deposit of metal vapour or oxide upon them, due to the blowing of the fuse, can be easily removed. Rigid asbestos tubes should either be discarded when fouled, or be provided with removable asbestos paper liners. Short lengths of loosely woven asbestos tubing, which can be slipped over the wires, and which fit them freely, give excellent results for the larger sized tinned copper wires, damping out the arc and limiting the scattering of the molten metal; allowance, however, must be made for the effect on the fusing current. Although the semi-enclosed fuse prevents the indiscriminate scattering of the molten particles on short circuit, yet nothing short of complete enclosure will prevent the metal being blown out of the open ends of the tube or holder. Fuses of this type at present on the market may be said to successfully withstand short circuit at higher voltages than the open type, although in most cases their fusing current is somewhat unreliable.

Enclosed Fuses.

Enclosed or cartridge fuses, in which the wire is surrounded by a tubular sheath with closed ends, have been developed from the Edison plug fuse. The tubes are usually loosely packed with an incombustible filling. Although the primary function of the filling is to smother the arc, it has also an important effect in reducing the violence of the explosion on short circuit. This is due to the heated gases being driven into the interstices of the filling and being thereby rapidly cooled. At the present time these fuses may be divided into two classes according as the fuse is entirely surrounded by the filling along its whole length, or is passed through a small air chamber usually located at its centre, the remaining spaces being occupied by filling. The construction of some American types is shown in Fig. 26. In the packed fuse it is evident that the molten wire receives a considerable amount of support from the filling material, and in consequence it may retain its continuity until it is volatilised, when it

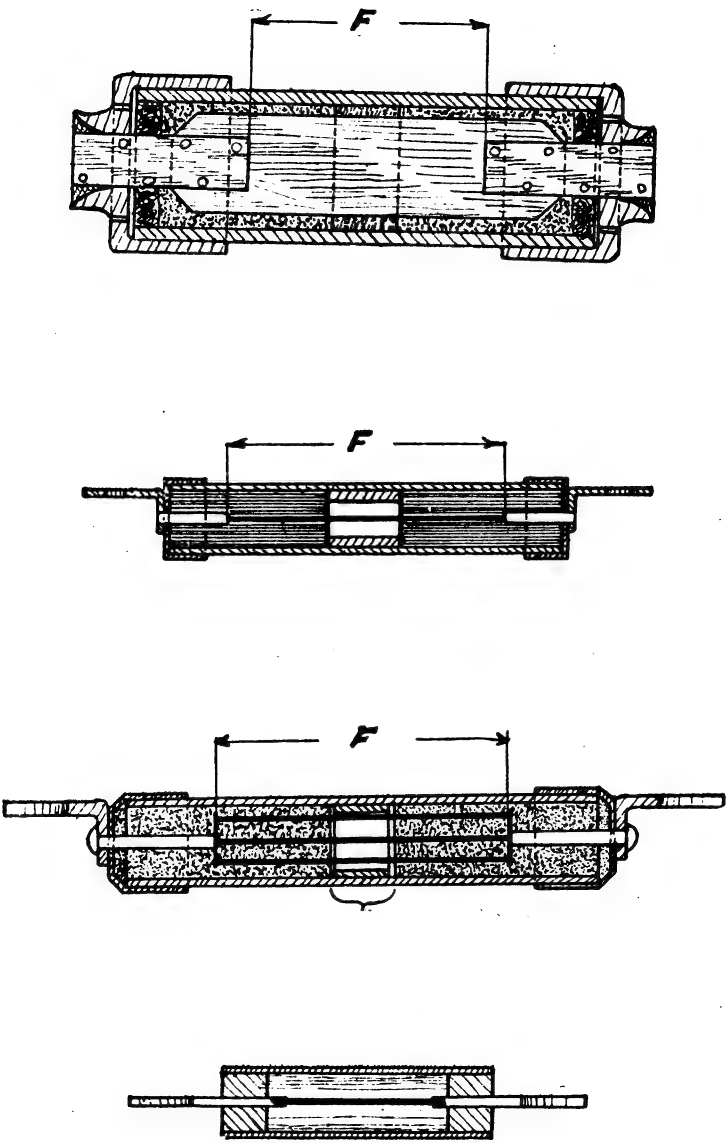

FIG. 26.—Enclosed Fuses.

may be carrying a current large enough to give rise to unpleasant effects, both in the circuit and in the fuse-holder itself. With a short length of the wire passing through a central air-chamber the wire has a better chance of rupturing, provided that the length of wire in the chamber is not too short, and that the metal employed is not too easily

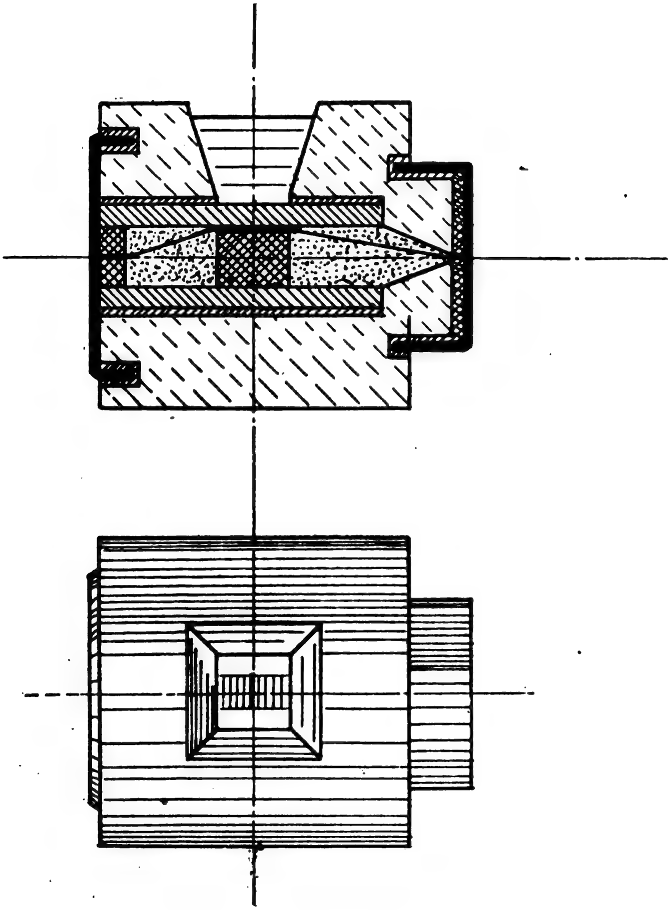

FIG. 27.—Siemens Cartridge Fuses (large size).

oxidised. Sachs* makes a great point of surrounding the wire with a material capable of entering into active combination with it when in the molten state. He mentions borax as an ingredient which acts as a flux on the oxide coating, and states that the other ingredients require careful selection. An analysis of the filling in two types of enclosed fuse obtainable in this country disclosed in one case nothing

* *Journal Amer. Inst. Elec. Eng.*, vol. 17, page 131, Feb., 1900.

more startling than a mixture of crushed limestone with (probably) fire-clay or ground slag.

It is difficult to see what chemical action such a mixture could have upon a zinc strip, which was the material used in this instance. In the second case where tin-lead alloy wires were employed, the filling consisted of about 50 per cent. sodium carbonate and 50 per cent. bone ash. As bone ash, however, only absorbs lead oxide freely at a temperature between 900° and 1,000° C., the wire would have to be raised to this extremely high temperature before absorption would take place. It seems probable, therefore, that the action of the filling is largely mechanical, and also that owing to the decomposition of an ingredient such as sodium carbonate gas may be given off, and so render the thread of molten metal discontinuous.

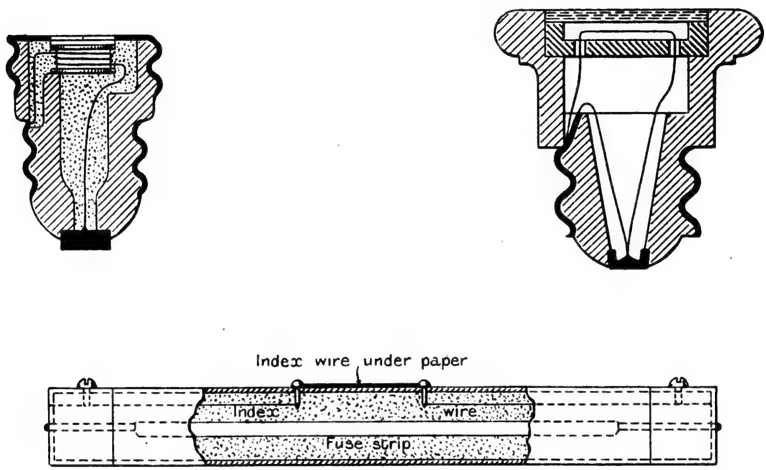

FIG. 28.

The Germans have developed very complete systems of cartridge fuses in which emery or French chalk are used as fillings, and porcelain as the jacket material. These fuses are extremely compact, and are non-interchangeable, both for voltage and current-carrying capacity. The construction of the large size Siemens cartridges is shown in Fig. 27, and samples and particulars are laid upon the table.

With enclosed fuses of all kinds it is necessary to have an indicator to show whether the fuse has blown or not; this usually takes the form of a very fine wire in parallel with the fuse wire, and arranged so as to be visible to the operator. Examples of these indicating devices are shown in Fig. 28.

The subject of enclosed fuses is a somewhat wide one, and the authors hope to make it the subject of a separate investigation, and prefer for the present not to express any more definite opinions in the matter.

General Considerations.

Tinned electrolytic copper should be used exclusively, except in the case of enclosed fuses which have been designed for use with metals of a low melting point.

All fuse-holders should be marked with their normal carrying

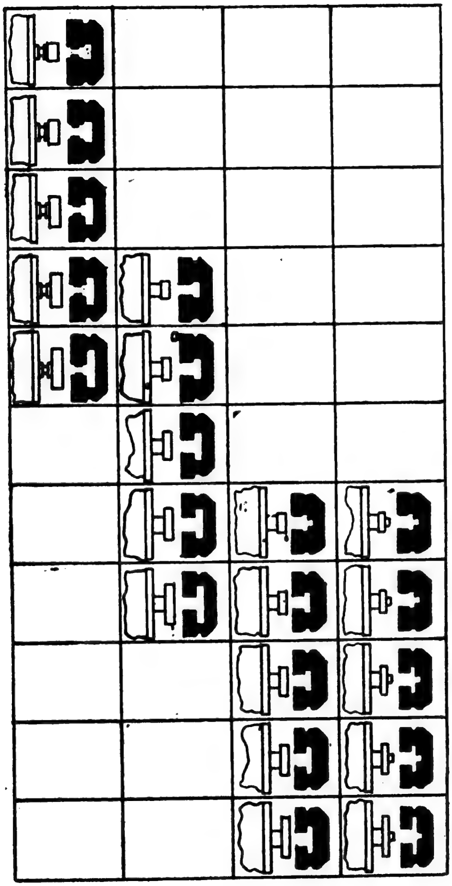

Fig. 29.

capacity in amperes (50 per cent. of the normal fusing current*), the voltage of the circuit for which they are intended and the gauge of the wire employed. Fuses should be screened from each other by incombustible septa either on the holder or between the fuses.

Distribution boxes should have ample air space, and be lined with

* For large fuses of several hundred amperes it is not necessary that the fuse should be set for as much as 100 per cent. excess current, as such circuits usually include an ammeter and are under some sort of supervision.

incombustible material, such as asbestos or Uralite on exposed wood surfaces.

The length of clear break or the minimum distance from metal to metal of the terminals should not be less than 2½ inches for circuits up to 220 volts for open fuses up to 20 amperes, with an additional half inch for every 15 amperes up to 110 amperes.

Small fuses should be non-interchangeable, both for voltage and fusing current.

There does not seem to be any necessity to extend the non-interchangeability for current to the larger sizes where special fittings are necessarily employed, and probably the following ranges should suffice :—

Normal fusing current } 3, 5, 10, 15, 20, 30, 45, 60, 80, 100 amperes.

Non-interchangeability may be secured in a number of ways. In the method adopted by Mix and Genest for their plug fuses, the plugs are fitted with a specially profiled ring which has to pass through a template of the same shape in the socket before the plug can be screwed home.

Fig. 29 shows a range of slots through which the contact pins of the large size Siemens cartridges have to pass. These cartridges are for use with the inclined jaws shown in Fig. 25. The non-interchangeability of these fuses from 0·5 to 10 amperes has been effected in a very simple manner, Fig. 30, by making the lower contacts in the form of a round pin, the diameter of which is different for different currents, and by providing the bases with gauge rings which fit the pins. For higher voltage the cartridges have stepped pins and rings with raised rims, as shown in the figure.

Contrasting the open and semi-enclosed types with the cartridge type for distribution boards for lighting purposes, the latter type is certainly more costly for replacements, and also for first cost, although as things stand at present it presents several advantages over the systems in vogue. A double-pole distribution board of this type with four branches is shown in Fig. 31. For outside work the cartridges can be placed in bell-shaped insulators, which act as weather covers, Fig. 32. In this country we are accustomed to regard the fuse-holder as a permanent fitting, and like to replace the wire ourselves when the fuse blows—not unfrequently with a larger size of wire. Our system has its advantages, and if made to conform with a set of regulations issued by this Institution for the construction and testing of fuses should prove quite satisfactory.

With regard to house service boxes, the box should be of metal with a lining of insulating and refractory material capable of resisting the action of an arc. Many of the enamels now used are liable to chip off when heated locally, with the result that the arc often gets through to the case. Ample air space should be allowed between the fuse fittings and the inside surfaces of the box. The question of air space is important with reference to the persistence of the arc. The heated

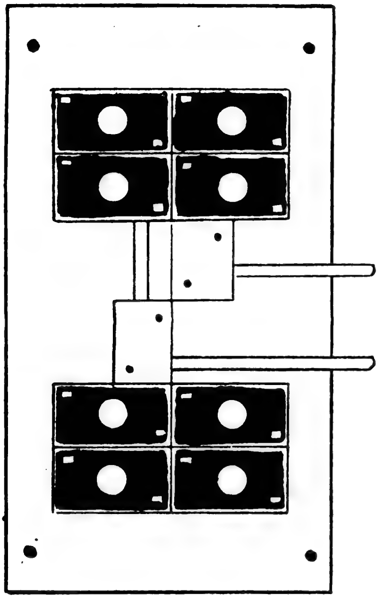

FIG. 31.

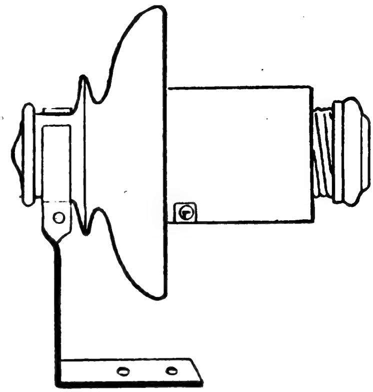

FIG. 32.

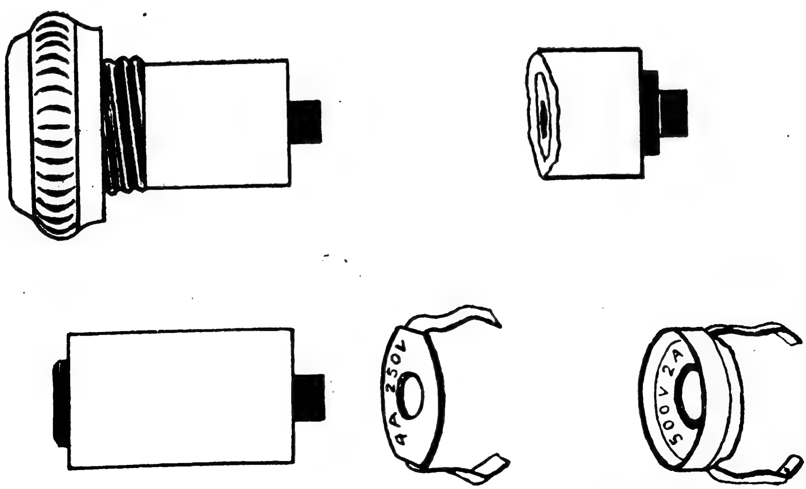

FIG. 30.

air and vapour should be given a chance of getting away. In this connection there is no reason why screened vent-holes should not be employed; this would promote a rush of air which should tend to rupture the arc. With open fuses in metal boxes the break should be at least 4½ inches. For house and motor services the enclosed fuse seems to offer considerable advantages over other types where large currents are required, and with pressures up to 400 volts, their chief drawback at present being the difficulty and cost of refilling the cartridges.

Testing of Fuses. Normal Fusing Current Tests.

In order to secure a common basis for the testing of copper fuse wires for normal fusing current, experiments were made to determine the ratio between the current necessary to bring a given wire to red heat (in diffused daylight) and its normal fusing current. As expected, this ratio was found to be constant, being equal to 0·75 for tinned copper wires of such length as to be independent of the cooling of the terminals. The normal fusing current of a wire of given length and environment has already been defined as "the minimum current required to fuse the wire in such a time interval as shall be necessary for the wire to have attained its maximum steady temperature." If, therefore, we raise the wire rapidly up to red heat we know that it is then carrying about 75 per cent. of its normal fusing current; the remaining 25 per cent. must then be added gradually at such a rate that the wire can attain a steady temperature as the current is increased. Large wires naturally require a longer time for this purpose than small ones.

Open-type fuses in which tinned copper wire is employed should be tested for normal fusing current in the following way: The wire in its holder should be screened from draughts, and the current raised until the first appearance of redness at the centre of the wire is observed in diffused daylight; this is the "red-heat current," and should be noted. The wire should be brought up to redness fairly rapidly—say in half a minute. For wires with normal fusing currents up to 20 amperes (up to No. 24 S.W.G.) the current should then be gradually and regularly increased at the rate of $\frac{1}{20}$th of the "red-heat current" per ten seconds. For wires with normal fusing currents from 20 to 120 amperes (Nos. 24 to 26 S.W.G.) the current should be increased at the rate of $\frac{1}{40}$th of the "red-heat current" per ten seconds. The above method of procedure will be found to allow ample time for the wires to attain a steady temperature.

For semi-enclosed and enclosed fuses the time interval necessary to bring them up to a given temperature will depend upon the environment of the wire, and should be ascertained by experiment.

Sachs * made experiments to determine the carrying capacity of fuse strips such as used in his solid packed "no ark" fuses, when covered with the environment, and when entirely air surrounded and exposed; he has shown with the several sizes of strips tested that the current-

* *Trans. Amer. Inst. Elect. Eng.*, vol. 17, page 131, Feb., 1900.

carrying capacity of the strip is the same whether it is encased or not. The smaller fuse strips show a slightly increased capacity when encased. His results are shown in Table XII.

TABLE XII. (Sachs).

Rating Tests of 500 *Volts* 40 *Amperes Fuse Strips.*

Fuse and terminal wires $5\frac{3}{4}$ inches between contacts.
Distance between centres of posts, $6\frac{3}{4}$ inches.
Terminals, 0·11 inch diameter.

	Tube.	Fuse.	Filling.	Run at	Time.	References.
				Amps.		
Enclosed	$\frac{3}{4}'' \times 5\frac{3}{4}''$	·018 × ·13 × 3″	All active	40	1 hr.	
		”		50	55 sec.	Opened.
		”		50	$3\frac{1}{2}$ min.	Opened.
Exposed to Air	None.	”	Air	40	15 min.	
			”	50	12 sec.	Opened.
				50	25 sec.	Opened.

It would appear, from a consideration of the above table, that for enclosed fuses with a certain overload, that the ratio of the time interval for blowing when in a hot and cold state respectively is about 1 to 4, whereas with the strip exposed to air it is about 1 to 2.

Short-circuit Tests.

Short-circuit tests on fuses should be made as far as possible under actual working conditions, and with a voltage 10 per cent. in excess of the circuit voltage for which the fuse is intended. It has been shown that the current rush on short circuit may be as much as twenty times the normal fusing current of the wire or forty times its normal carrying capacity when rated to blow with 100 per cent. excess current, so that in order to simulate working conditions a current of this magnitude should be arranged for. This may be done by substituting for the fuse a length of wire of greater carrying capacity, but of approximately the same resistance, and adjusting the current through this to the desired value by means of a regulating resistance and an ammeter, then replacing the fuse and short-circuiting through a heavy switch.

In no case should the short-circuit current be arranged for less than 400 amperes. The source of current and the resistance of the conductors must be so arranged that up to the moment of melting of the fuse the total drop of pressure shall not exceed 2 per cent.

Wherever possible facilities should be given at the central station or one of the sub-stations serving the district for the testing of types of fuses proposed for consumers' premises. In this case the pre-

arrangement of the short-circuit current may be dispensed with and the fuse connected with heavy leads to the mains or bus-bars, arrangements being made for switching in or out as desired.

Where fuses are proposed to be used on each pole of a circuit they should be tested in series. House service fuses should be tested with the box covers in position.

Fuses should also be tested for arcing with currents slightly in excess of their normal fusing current, the current being increased gradually in the way already specified for determining the normal fusing current.

Conclusion.

It has been shown that a fuse wire may be subject to a number of influences which affect its fusing current to a greater or less extent. Most of these disturbing effects are small, ranging from about 3 to 12 per cent., and it may be urged that with a device which becomes operative with excess currents of 100 per cent., errors of the order named may be safely neglected. If these sources of error were present singly this might be so, but this is rarely the case, and it is to the accumulated effect of several of them operating together that the so-called unreliability of fuses is due. The maximum errors due to various causes in open and semi-enclosed types of fuses are scheduled below.

	Maximum per cent. error.
Preece's Formula: Re-determined values.	
Tinned copper wires at 100 amperes	19% high
„ „ „ 20 amperes	Correct.
„ „ „ 3 amperes	20% low.
Vertical as against horizontal position. Tinned copper	5 per cent.

Effect of length and cooling due to large terminals. Percentage increase over fusing current for a length which is independent of cooling of terminals.

Tinned Copper.	Lengths.					
	6″	5″	4″	3″	2″	1″
	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.	Per cent.
For 115 amps...	2·5	6·5	15	31		
For 10 amps...				2	5	30

Effect of Terminals. Increase in fusing current for heavy terminals as against light ones for tinned copper.

For 115 amps. length 4½ inches	6 per cent.
For 10 amps. length 2½ inches...	3 „
For 10 amps. length 1½ inches	5 „
Vibration. Tin and lead, decrease in fusing current	3 „
Enclosure in tubes. Decrease in fusing current	12 „

Contact with porcelain.

Tinned copper in semi-enclosed porcelain fuse-holder :—

(1) Wire arranged so as not to touch the porcelain, increase above normal fusing current = 2 per cent.

(2) When pulled tight and close to porcelain FC increased 10 per cent.

Lead wire arranged as above in (1) increase in FC = 18 per cent.

Arranged as in (2) above, increase = 52 per cent.

Tinned copper in holder of Damper type :—

Wire out of contact with porcelain, FC increased 5 per cent.

Wire in contact with porcelain, but without damper, FC increased 14 per cent.

Wire in contact with porcelain and damper, FC increased 24 per cent.

The fuse is an extremely simple device, and it is perhaps due to this fact that it has not been treated with the necessary care. All experiments with fuses should be carried out with the greatest care if accurate results are to be obtained, and the same care should be exercised in their design and installation.

The authors' thanks are due to the Committee of the Municipal School of Technology, Manchester—in the Electrical Laboratories of which institution these tests were carried out; and to Messrs. C. C. Metcalfe, F. Morton, J. and R. Cunliffe, and B. E. Stott for assistance in the experimental work; to Mr. Bertram Stott for assistance in the preparation of the drawings; and to Mr. E. L. Rhead for the analysis of the materials. Their thanks are also due to Mr. S. L. Pearce (the City Electrical Engineer), Mr. S. Skinner, the Siemens Electric Appliances Ltd., Messrs. Drake & Gorham, Veritys, Dorman & Smith, and the General Electric Company for the loan of fittings and fuses.

ANALYSES.

Report by Mr. E. L. Rhead, of the Metallurgical Department of the Municipal School of Technology, on the composition of samples of fuse wires employed by the Authors, and on the fillings for enclosed fuses.

Thick Tin Wire.

Constituents found per cent.

	Per cent.
Lead	0·201
Copper	0·280
Iron	0·035
Zinc	traces
Arsenic	traces
Tin (*a*)	99·4

Thin Tin Wire.

	Per cent.
Lead	0·131
Copper	0·118
Iron	0·086
Zinc	traces
Arsenic	traces
Tin (*a*)	99·75

Aluminium Wire.

Iron	0·098
Calcium	0·09
Magnesia	0·034
Silica	traces
Alkalis	traces
Aluminium	99·8

Copper Wire (Tinned).

Tin coating	0·51
Iron	traces
Arsenic	traces
Copper	99·44

Filling for Enclosed Fuses.

Sample A White powder—

	Per cent.
Soluble in water after drying	49·17
Insoluble	50·83

The Soluble part is Sodium Carbonate.
The Insoluble part is Phosphate of Lime (Bone Ash).
The Powder contains no Borax.

Sample B Grey powder—

	Per cent.
Soluble in Water	0·050
Insoluble in Water	99·95
Soluble in Hydrochloric Acid	63·81
Insoluble in Hydrochloric Acid	36·19
Soluble Silica	0·885
Ferric Oxide and Alumina	14·98
Lime	24·35
Magnesia	1·835
Carbon dioxide	21·2
Phosphoric Acid	traces

Free metallic iron exists in the material.

For

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Mr. Taite. Mr. C. D. TAITE (Chairman): I think that the skin effect of lead and tin fuses is not generally known, and the fact that numbers deduced from Sir William Preece's well-known formula are found to be so much in error, shows the need of a paper on the subject. It is a noteworthy fact that the variety of fuses and fuse-holders on the British market is considerably larger as compared with the number of varieties in use elsewhere. I am not in favour of the idea of doing away with the old-fashioned clamping screws, as in an emergency I believe this design to be useful.

Mr. Andrews. Mr. L. ANDREWS: As an instance of the unreliability that fuses possess, I may mention an occurrence at Hastings when, with two fuses practically in series, one rated at 250 amperes and the other at 70 amperes, the heavier fuse blew upon a short occurring at a transformer on the far side of the lighter fuse. The explanation, I think, is that the main fuse, which had been working some time, had become warm, whereas the 70-ampere fuse was comparatively cold, and the extra rush of current was sufficient to melt the main fuse before the smaller one. Fuses for arc lamps are very unsatisfactory on account of the large current taken when the lamps are first switched on, and I think the best thing is to put in a fairly big fuse and inspect the lamp at short intervals. I am much surprised that the effect of mechanical injury was not more marked, especially where the wire was cut almost in two. The fact that there is more trouble with alternating-current than continuous-current fuses is, I believe, not due to deterioration of the wire, but is the result of vibration at the contacts, which thereby become loosened; even lock nuts do not entirely prevent this. I agree with Mr. Taite as to the convenience of the old-fashioned clamp arrangement. I should advise a reference to Professor B. Hopkinson's paper in the minutes of the Institution of Civil Engineers, for some interesting particulars concerning carbon break cut-outs, and magnetic blow-out apparatus.

Dr. Garrard. Dr. C. C. GARRARD: I think that designers of low-tension fuses will find nearly all the data they require in the paper, which would have been additionally useful if the experiments had been extended to fuses of larger current-carrying capacity. With currents of 200 amperes and upwards the chief difficulty is the watt consumption and heating, as with a fuse of smaller size about 50 watts is the maximum allowable liberation of heat, and with a larger watt consumption the neighbourhood of the fuse gets excessively hot. With the object of standardising fuses I have been plotting curves of watt consumption and current during the last three years, and I think my method of testing corresponds more nearly to working conditions than that advocated by the authors, as it is based on the principle that any current below the melting-point value can be kept on for an indefinite period without the fuse blowing. I consider it is useless to rate the carrying capacity of a fuse at 500 amperes if it will melt at 400 amperes passing for two hours, and this result may be obtained with the author's method. I have known a 10,000-volt rise to take place on a very inductive 220-volt circuit when a 90-ampere fuse blew. This rise was measured by a

spark gap, and pieces of paper interposed were pierced by the spark, showing the destructiveness of the excess voltage. Such a fuse would therefore cause damage to the apparatus that it was intended to protect should it be needed to open the circuit. Dr. Garrard.

Mr. E. W. COWAN: I consider terminal capacity a great factor in determining the capacity of a fuse. From my experience, a fuse is useless in protecting an armature from a heavy reverse current from a battery. Mr. Cowan.

The principle of shunt fusing was insufficiently considered, as to the advantage of taking no current when working, but making the final break in a safe place. Circuit-breakers for heavy currents are preferable to fuses, as the former open at once on dead shorts, and use a time element lag for less deadly effects. I also prefer long drawn out breaks to rapid snaps, which induce rise of pressure among other things.

Mr. A. C. CORMACK: I am of opinion that atmospheric temperature would influence a fuse, and that a multiplicity of small fuses is better than a single large one. Terminal effects have got fuses their bad name for unreliability. I do not think that 100 per cent. excess current should be allowed on all circuits, but one objection to a less percentage is that of lost watts. Automatic circuit-breakers would open nearer the mark, although they sometimes stick; but where a fuse can be relied on to 50 per cent. or 60 per cent. it is to be preferred to a circuit-breaker. I should advocate the use of a circuit-breaker and a fuse in series. Mr. Cormack.

Mr. H. G. BAGGS: I feel grateful for the new formula evolved by the tests, although I think Sir William Preece's time-honoured $C = Ad^{3/2}$ is still good enough for workshop experiments. I think the time is coming when circuit-breakers will take the place of fuses. The non-interchangeability of fuses is not desirable from a manufacturer's point of view, as circuits are sometimes used for different ratings as time goes on. Mr. Baggs.

Mr. C. C. ATCHISON: I appreciate the results of the experiments, as I have myself tried to make similar ones, but I found that too much time was required. I consider that every type of house fuse on the market has its defects, and consequently some corporations have made their own designs. I think changing fuses every three months would involve far too much work, even in smaller towns. If fuses were properly standardised, cut-outs would be used less than they are at present. As to materials for fuse-holders, I have tried teak, charred on the inside to prevent combustion, and found it preferable to porcelain. Enclosed fuses were very sparkless and noiseless in operation, and I have met with the case of one blowing quite close to me and only being discovered by the effect on the machines. Mr. Atchison.

Professor A. SCHWARTZ (*in reply*): I think that Mr. Andrews has indicated the right source of trouble in fuses on alternating-current circuits in ascribing the effects to the loosening of the terminals rather than to Sir D. Salomons' contention as to change in molecular structure in the wire. With regard to the effect of mechanical injury to the fuse wire, Professor Schwartz.

Professor Schwartz.

this is certainly very much smaller than one has been led to expect. In the case of a blow the radiating surface of the wire is increased, and in the case of a cut this is also the case to a small extent, owing to the exposure of the cut surfaces; and although the sectional area is considerably reduced, with a consequent increased liberation of heat locally, a large portion of this heat is conducted away by the neighbouring portions of the wire which are at a much lower temperature. In reply to Dr. Garrard, we recommend that for large fuses the current in a single strip or wire be limited to 100 amperes, and the wires placed in parallel with sufficient spacing to allow of efficient cooling. The carrying capacity of a fuse as defined by us is that current which the fuse is capable of carrying indefinitely without undue heating or deterioration, and we further recommend that this be taken as 50 per cent. of the normal fusing current as defined by us, consequently a fuse rated to carry 500 amperes would do so for many months. The atmospheric temperature effect I consider to be inappreciable when dealing with temperatures of the order of 1,000° C. With regard to Mr. H. G. Baggs' contention that standardisation as to carrying capacity is not desirable owing to the need in many cases for increasing the capacity of the circuits after installation, I may point out that the devices for limiting the capacity of the circuits are easily made interchangeable to authorised persons, and to these it would be simple to alter the standard fixed fittings in the fuse-box by the substitution of other standard fittings of greater or less capacity. I disagree with Mr. Atchison as to the inherent unreliability of fuses, and I think that careful standardisation would do much to remove many of the causes of unreliability from which fuses are at present suffering. I do not advocate putting fuses in oil, but prefer enclosing them in porcelain for special situations as collieries, etc. A constant environment such as with an enclosed dust fuse adds to the constancy and reliability of the fuse, and I believe that this class will come more and more to the front.

BIRMINGHAM LOCAL SECTION.

NOTES ON HEATING AND SPARKING LIMITS IN VARIABLE SPEED MOTORS.

By A. H. BATE, Associate Member.

(*Paper read at Meeting of Section, March* 15, 1905.)

It is an article of faith with most engineers that it does not pay to drive each machine tool by its own motor except where large powers are required, and accordingly in this country the "individual drive" is comparatively little used. In America, however, the case is different. There the advantages of electrical power are more generally recognised by manufacturers, and, owing to the greater cost of labour, a reduction in the time taken for each operation has more influence on the cost of production than is the case in this country.

As a long range of speed variation is only required with the individual drive, it is not surprising that more attention should have been paid to this subject in America than here. The introduction of the high-speed tool steels has so increased the power required by many machines that, although the old rule about grouping small power machines on short lengths of shafting still holds good, it applies to a smaller proportion of the total number of machines that have to be driven. In the case of some of the larger tools a variable speed motor is almost a necessity if the work is to be done to the best advantage. Take for example the case of a 16-in. roughing lathe. Four years ago such a tool would have taken about 5 H.P. from the shafting, while now it requires 30 to 40 H.P. The heavy belt for such a power as this cannot conveniently be shifted on a cone pulley, and as no reliable form of variable speed countershaft has yet been invented, a variable speed motor is the only means available for filling in the gaps between the speeds given by the various combinations of gearing.

In view of the greatly increased demand that is likely to arise for such motors when engineers have had time to realise that the labour cost in certain classes of work may be reduced by 20 per cent., and sometimes even by 40 per cent., it is hoped that a paper on this subject may be of some slight service, even though it contains nothing new or in any way original.

Broadly speaking, there are three ways of varying the speed of a shunt motor.

(1) Varying the magnetic flux through the armature, either by changing the reluctance of the magnetic circuit, or by altering the exciting ampere turns with a field rheostat.

(2) Varying the pressure applied to the armature, either by resistance in series with the armature, by the multiple main system, or by a reversible booster arrangement.

(3) Changing the number of turns on the armature by providing two commutators and two sets of windings connected in series or in parallel.

Each of these methods has characteristic features that fit it for particular purposes and limitations as to heating and sparking which make it unsuitable for other purposes. Before discussing the way in which these methods affect the heating and the sparking limits, we will consider the factors that determine the sparking limits.

In the short interval of time that the coil is short-circuited under the brush—that is, in from about 0·005 to 0·001 of a second—the current in the coil has to be reduced from its full strength to zero, and brought up to its full strength in the opposite direction. If there was no self-induction in the coil this reversal of the current would not involve the expenditure of any work, and the process of commutation would be extremely simple. The commutator might have as few sections as you please, and the contact resistance between the brush and the commutator might be low or high, yet the current would be reversed at a uniform rate by what we may call the slide-valve action of the brush. In trying to form some conception of what goes on during commutation it is convenient to consider the forces concerned in this slide-valve action and those relating to the self-induction effect separately. If the brush width w is equal to q, the width of one segment plus mica, the full current of the motor $= 2\ c$ will pass from the brush into this segment when they coincide. An E.M.F. e is required to overcome the contact resistance between brush and segment, and an E.M.F. E is required to force the current c through the resistance of the coil itself. Neglecting the self-induction effect for a moment, when the commutator has moved forward so that the brush covers four-fifths of one segment and one-fifth of the other segment, the resistance of contact will be increased in the ratio of five-fourths to one, and as the current c and also E.M.F. E are both proportionally reduced, the value of e remains unchanged. In the same way, when the brush bears equally on both segments the current in the coil is halved, and as the resistance of the contact is doubled, the value of e is still unchanged. The value of E has no bearing on the problem of commutation, because if the force is great in a forward direction at the beginning of commutation, it is equally great in the reverse direction at the end.

We will now consider the dissipation of the energy stored in the coil due to self-induction, assuming that the brushes are so placed that the stray magnetic field generates no E.M.F. in the coil either to assist or to retard commutation. We will write E_s for the E.M.F. generated by reversing the total linkage through the coil in time t. While the coil is short-circuited this E.M.F. sends a current that passes from one segment into the brush and from the brush to the other

segment and round the coil. In passing from segment to brush and brush to segment this current is opposed by the E.M.F.'s ε_1 and ε_2 due to the resistances of contact between the brush and the respective segments. When the brush is just coming into contact with, and when it is just leaving, a segment, the sum of these resistances is very high, and when the brush bears equally on each segment it is a minimum. The E.M.F. e due to the main current passing through these resistances need not be considered, because at one segment it opposes and at the other segment it assists the short-circuit current. If the contact resistances between brush and segment are to be solely relied on to absorb the electro-magnetic energy stored in the coil, the average value of the E.M.F. due to the short-circuit current passing through these resistances must be equal and opposite to the average value of the reactance voltage E_s.

In modern dynamos and motors the contact resistance does effect the commutation satisfactorily, even when the stray flux is opposing and not assisting the reversal of the current. As the contact resistance of the brushes can only be varied within narrow limits, it is necessary to so reduce the self-induction of the coil that the value of E_s is not too great. Messrs. Parshall and Hobart were, I believe, the first to point out the importance of reactance voltage as a criterion of the sparking limits, but their method of calculating this value is too cumbersome for practical work. In a paper read at the International Engineering Congress at Glasgow, Mr. Hobart described a series of tests on the inductance of armature coils under various conditions. For the part of the coil embedded in the slot and with a slot three times as deep as it is wide his results show that there are about ten lines of force per ampere turn per inch of effective length of core, and a corresponding number of about two lines per inch for the part of the coil outside the slot. Calling these values respectively f_s and f_a, we have

$$\text{Self-induction of one turn of the coil} = f_s l_s + f_a l_a,$$

and

$$\text{Mutual induction} = (f_s l_s + f_a l_a) m_1 m_2 \frac{p}{b}.$$

Multiplying by the maximum current in the coil, we get

$$\text{Total linkage} = (f_s l_s + f_a l_a) m_1 m_2 \frac{p}{b} c.$$

If we assume that the current changes according to a sine function of time, it is easy from the above to arrive at the reactance voltage. The only excuse for doing so is that we do not know at what rate the current does actually change and the sine law is convenient, and gives fairly good results in practice.

As t stands for the time of half a cycle, the periodicity is $\frac{1}{2t}$ cycles per second, and assuming the sine law, for want of better, the E.M.F. induced in the coil by reversing the above linkage—that is to say, the reactance voltage—is

$$R_s = (f_s l_s + f_a l_a) m_1 m_2 \frac{p}{b} c \times \frac{2\pi}{2t}.$$

To put this into a more convenient shape for every-day use, we may express t in terms of the number of commutator segments and revolutions per minute by writing $t = \frac{60\,W}{s\,q\,n}$. Then, as $m_2 = m_1\,\frac{2\,W}{q}$, the values of W and q cancel, and we have

$$R_s = 0{\cdot}1046\,(f_s\,l_s + f_a\,l_a)\,m_1^2\,\frac{p}{b}\,c\,s\,n \times 10^{-8}.$$

The R.M.S. value of the reactance voltage would be $\frac{R_s}{\sqrt{2}}$ if the change followed a sine law. If the stray field is inducing an E.M.F. E_m in the coil while commutation is taking place, to obtain perfect commutation we must have

$$\frac{R_s}{\sqrt{2}} \pm E_m = \epsilon_1 + \epsilon_2.$$

It is easier for most people to obtain a clear conception of a mechanical action than of an electrical action, and the writer has found it helpful to compare the electro-magnetic energy stored in the coil with the kinetic energy stored in a rotating drum. The speed of rotation of the drum then represents the strength of current in the coil, and the force required to reduce the kinetic energy to zero in time t may be called the reactance force of the drum. It is not difficult to construct a mechanical model in which the various E.M.F.'s concerned in commutation are represented by the force of friction of various plates on the drum.

In practice the reactance voltage calculated from the above formula gives a surer indication of the current and speed at which sparking will commence than any other criterion that has been advanced so far, but it is not an infallible guide in all cases. Tests of small bipolar motors give very uniform results even with extreme variations in the speed and power of the machine, but for some reason the reactance voltage at which a multipolar motor will commence sparking is not so constant. This may be due to an incorrect estimation of the value of f_s, or it may be that the departure from the sine law is greater in multipolar machines than in bipolar. There is also the question of brush width, which certainly has an influence on the sparking limit quite apart from any question of current density, and as will be seen from the formula above, this has no effect on the reactance voltage. It would seem, then, that there is scope for an improvement in the method of calculating the reactance voltage, and this will probably come when we know more about the way in which the current changes and can do without the sine-wave assumption.

When, however, the reactance voltage is used as an indication of the current at which any one motor will commence to spark when the speed is varied by altering the terminal pressure or by varying the field strength, it gives remarkably consistent results. Tests were made on a 2½-H.P. bipolar, shunt-wound motor designed to run at 600 revolutions per minute on 220-volt mains, this speed being variable to 1,800 revs.

by weakening the field magnets. In the first test the armature was run with 220 volts across the brushes. and readings were taken of the current that just caused visible sparking when the field strength was varied to give speeds ranging from 560 to 2,100 revolutions per minute. In the second test similar measurements were made with 110 volts across the armature. In this case the slowest speed was 260 revolutions per minute, corresponding to about 1¼-H.P., and the highest speed was 1,800; that is to say, the speed ratio was rather more than 6 to 1. In the third test the fields were not excited and the armature was turned round by a second motor. Measurements were taken of the current that produced sparking as before when the armature was run at various speeds. From considerations of reactance voltage, one would expect that the current at which sparking commences would be inversely proportional to the speed and the results of these three tests show that this is true, not only for such ordinary variations of voltage and field strength as were used in the first two tests, but also under the extreme conditions obtaining in the last test. This is not what one would have expected to find, because the brushes were set approximately in the neutral position, and there the stray field would set up an E.M.F. opposing commutation.

Assuming, then, that reactance voltage may be taken as a safe guide for studying variable speed motors, we will proceed to notice its effect on the horse-power that can be taken with different methods of speed control. For purposes of comparison we will take a motor which, if wound for constant speed, would give 10 H.P. at 1,000 revolutions per minute. The armature windings and commutator segments are supposed to be so proportioned in each case that the sparking and heating limits coincide at the speed for which the commutation is poorest. It will be sufficiently correct for our purposes to take the core losses as being proportional to the product of speed and flux density in the armature core. For the sake of simplicity we will neglect the change in efficiency as the load varies and also the improved ventilation of the armature that is obtained with higher speeds and take the heating limit as being conditioned by the $C^2 R$ loss alone. The correction for these quantities depends on the construction of the particular type of motor concerned, and does not seriously affect the result.

The table on p. 426 shows the horse-power of such a motor as limited by heating and sparking.

Attention may be drawn to the last arrangement given in this table. The speed range is greater than is obtained by a double-wound armature with equal windings, and as there are three possible combinations instead of only two, the intervals in the speed that have to be filled in by field regulation are not so wide. The power available from heating considerations is certainly less than it would be if equal windings had been used, but this would not be a serious drawback for many purposes where the load is intermittent. There is one weakness, however, namely, that the commutation is poorest at a middle speed instead of at the highest speed. It certainly seems that this arrangement deserves more attention than has been given to it. When selecting the method of obtaining variable speed it is necessary to take the load factor into

Method of Control.	Speed =	330	500	750	1,000	1,250	1,500
Variable field by rheostat or moving poles.	Heating	—	5	5	5	5	5
	Sparking	—	15	10	7·5	6	5
Variable pressure by reversible booster.	Heating	—	5	7·5	10	12·5	15
	Sparking	—	15	15	15	15	15
Variable pressure by multiple mains. Three-wire system.	Heating	—	5	5	5	110 volts	
	Sparking	—	15	10	7·5		
	Heating	—	—	220 volts	10	10	10
	Sparking	—	—		15	12	10
Double-wound armature. Equal windings.	Heating	—	5	5	5	Series	
	Sparking	—	15	10	7·5		
	Heating	—	—	Parallel	10	10	10
	Sparking	—	—		15	12	10
Double-wound armature. Winding A, 2 turns per section. Winding B, 1 turn per section.	Heating	3·3	3·3	Series			
	Sparking	8·2	5·5				
	Heating	—	4·1	4·1	4·1	A winding alone	
	Sparking	—	8·2	5·5	4·1		
	Heating	B winding alone			5·8	5·8	5·8
	Sparking				16·4	13·2	11

consideration. To illustrate the importance of this point we will compare the duty imposed on the motor by a lathe, a ram pump, and a planing machine.

In the case of the lathe, approximately the same power will be required at all speeds, but as there are usually considerable intervals of rest and light load in this class of work, the heating limits need hardly be taken into account. What is wanted is a motor that can deal with the same overload throughout its speed range. For this the regulation by a reversible booster would be the ideal method if the cost was not prohibitive. The multiple mains system meets the case fairly well, but the cost of extra cables and switchgear is only repaid when a fairly large proportion of the motors are required to work at variable speeds. One has therefore to fall back on regulation by varying the field, and this gives excellent results in practice in spite of the restricted overload capacity at high speeds. If the motor is liberally rated, overloads that cause sparking will not be frequent or of long duration in most cases and the brushes polish the commutator during the subsequent working at light loads.

In the case of the ram pump the load is likely to be continuous, and heating limits are therefore of more importance than considerations of sparking. As the power required by the pump increases with the speed, the double-wound armature with equal windings is obviously best for this purpose unless a multiple mains system is available.

The driving of a planing machine by a motor presents a more difficult problem. The load may be almost continuous, and at each reversal there is a very heavy overload for an instant. Mr. A. D. Williamson has, I believe, been successful in using the shunt-wound motor with variable field control for this purpose. The resistance in series with the field spools is short-circuited by a switch (operated by the movement of the table) during the time of reversal. The speed of the motor is thus reduced and the sparking limits proportionately increased just when the overload has to be dealt with.

LIST OF SYMBOLS.

b Number of circuits in the armature.
c Amperes in one circuit of armature.
D Diameter of commutator.
e E.M.F. due to current c passing through brush contact resistance.
$\varepsilon_1 \varepsilon_2$ E.M.F.'s due to short-circuit current passing through brush contact resistance.
E E.M.F. required to force current c through resistance of one coil.
E_m E.M.F. induced by stray field during commutation.
E_s E.M.F. of reactance.
f_s Lines of force per ampere per inch of coil in slot.
f_a Lines of force per ampere per inch of coil in air.
l_s Length effective of armature core (inches).
l_a Length of coil in air.
m_1 Turns in coil = turns per segment.
m_2 Turns of all coils simultaneously undergoing commutation.
p Number of poles in field magnet.
q Width of segment.
s Number of segments in commutator.
t Time, in seconds, occupied for commutation.
W Width of brush.

Mr. H. M. HOBART (*communicated*): The design of a motor for variable speed by shunt control is, in reality, the simplest case with which a designer has to deal. The reason is that, if the speed range is to be at all great, it is useless to set the brushes with a fixed angular displacement from the neutral position for the purpose of thereby assisting the commutation. The extreme case is met in the motor, which must run in either direction. It is my practice in such a case to design the motor with the brushes in the geometrical neutral point and with a sufficiently low reactance voltage to preclude sparking at the highest speed required for a given load. Mr. Bate's tests have also shown that in such a case, the current at which sparking commences is inversely proportional to the speed, and that this is so even in the extreme case of unexcited fields, the armature being driven by a motor. This case is met with in continuous-current potential regulators, which are coming into more and more extensive use to displace rheostatic control of large motors. Mr. Hobart.

Mr. Hobart. Returning to the motor for operation at varying speed by shunt control, it may be well to point out that it is preferable to choose as low a maximum speed as possible. That is to say, if it is required to drive a machine tool with a maximum speed of 100 r.p.m. and a minimum speed of 25 r.p.m., it would be well to choose a very low gear ratio, letting, for instance, if 10 H.P. is required, the corresponding speeds of the driving motor be 400 r.p.m. and 100 r.p.m., rather than, say, 1,000 and 250 r.p.m. This will be the more important the higher the voltage of the network. Thus, for a 440-volt system, it will be highly important to adopt the lower speeds, whereas for a 110-volt system, the higher speeds will give a good result. For 220 volts, the lower speeds would, on the whole, be preferable. In a contribution to the *Electrical Review*, 1903, p. 926, I have endeavoured to give a rough idea of this matter.

Mr. Hill. Mr. C. W. HILL (*communicated*): In addition to the methods mentioned by Mr. Bate for controlling the speed of motors, there is one which has been tried some years ago which does not appear to have attracted much attention. The method was devised by Mr. S. N. Rushmore in 1897, and although not intended specially for motor controlling it would appear suitable for that purpose. (Details of his experiments were given in the *American Electrician*, and there was also an article in the *Electrical Review* of April 14, 1899.) Mr. Rushmore's method consisted in using multipolar dynamos having parallel wound armatures in which the brushes, instead of being connected to feed a single circuit, were connected independently to separate circuits, the voltage and current in each of which might be varied without reference to the others. The machine on which the experiments were made was a four-pole machine feeding two separate circuits. It was shunt wound, the magnet coils being in two circuits corresponding to their respective pairs of brushes with regulating resistances for varying the voltage. With such an arrangement a development of the Ward-Leonard system seems possible. A single motor-generator set would be capable of serving several motors instead of only one, and each motor could be started, stopped, and regulated independently of the others. As an instance of the possible application of this method we may take the case of a couple of air compressors supplied with current from a four-pole generator. In such a case, by connecting the compressor motors on separate circuits the speed of each may be economically regulated over a wide range, and the starting arrangements would be simple. With regard to shunt motors in which the speed is regulated by varying the field, I have for about two years been using this type of motor for a purpose for which at first sight it would hardly seem suitable, namely, for the hoisting gear of cranes. Where a hoisting gear is in an inaccessible position, as in the case of the crab on an overhead crane, the series motor has drawbacks. To a certain extent it varies its speed according to the load, but as this extent is limited it is usual to fit speed change gear on the crab so as to increase the speed range. To change the gear it is, however, necessary to run the crab up to the cage, and in some cases it is also necessary for the driver to get up on to the platform. This involves so much trouble

that the change gear is seldom altered, and might in most cases be as well left off. If a shunt motor is used, the speed changes can be instantly effected without tróuble by means of a shunt regulating switch placed in the cage. In order to prevent the load running away when lowering with a series motor, an automatic mechanical brake is necessary which comes on when the load overhauls the motor. This is not required with a shunt motor, as the latter, when overhauled by the load, returns current to the circuit, and so automatically offers the right amount of resistance to keep the speed of lowering within the required limits. Mr. Hill.

On a 30-ton crane, to which I have fitted a shunt motor, the speed of lift can be varied from 4½ feet per minute for a full load to 19 feet per minute for the hook only. When lowering, with the regulating switch on the same positions the speed is a little greater than when hoisting. These are the speeds when the controller is full on, slower speeds being obtained on the intermediate steps. Thus, when lowering 30 tons, the speed on the first step is 9 inches per minute, and when full on the speed is 5 feet per minute, and at this speed the motor returns 20 amperes to the circuit the voltage of which is 220. The 30-ton crane is the first to which I have applied a shunt motor. It has worked very satisfactorily for nearly two years, and the same arrangement has since been fitted to several other cranes.

Mr. S. H. HOLDEN: I should like to ask if Mr. Bate has used reversing poles on motors in order to increase the sparking limit. Personally I have used them to great advantage in the case of a 70-H.P. motor, which was started up light, run for a few seconds heavily loaded, then stopped and reversed. Carbon brushes were used, placed in a central position. I advocate the use of series motors in many cases where machines are driven by a separate motor. They are specially suitable in the case of planing machines, as they give a powerful torque at reversal and are capable of taking a very heavy overload. Mr. Holden

Mr. A. H. BATE (*in reply*): I am much interested in Mr. Hill's description of the use of shunt motors for cranes. I think it is one of the many purposes to which variable-speed shunt motors might be applied. But I doubt if the average crane driver would take the trouble to vary the field rheostat. I have never worked with reversing poles, having regarded them as unnecessary for ordinary working, since good results can be obtained by the shunt rheostat with low reactance voltage and carbon brushes. I appreciate the suitability of series motors for driving planing machines. When using a shunt motor for this work it is important to get a fly-wheel effect and to make the commutating conditions very good. Mr. Bate.

BIRMINGHAM LOCAL SECTION.

COMMUTATION IN A FOUR-POLE MOTOR.

By J. K. CATTERSON-SMITH, Student.

(*Paper read before a Meeting of Section, March* 15, 1905.)

SYNOPSIS.

Introduction—Particulars of test—Armature winding of motor—Commutation of a four-pole wave-winding with two brushes—Light load and full load —Brush lifting—Commutation with four brushes—no load and full load curves for each brush—Current in coil during short circuit—Brush shifting forwards and backwards—Reactance voltage.

Since the introduction of continuous-current machinery the predetermination of the commutation qualities of a given design has been a matter of considerable uncertainty, owing largely to the lack of experimental data concerning the exact behaviour of the current in an armature coil during the period that its ends are under a brush. The chief reason for the scarcity of investigation in this direction has, no doubt, been due to experimental difficulties, but now that the "high frequency" type of oscillograph is available, the commutation curve and flux distribution can be obtained with little more trouble than the indicating of a steam engine.

When it is considered that out of the total number of continuous-current machines manufactured a large proportion, possibly 50 per cent., of these have their rating determined by commutation rather than by heating; that the size and range of variable speed motors, the range of voltage on generators, and the whole design of turbo-driven machines is determined chiefly by whether the commutation is sparkless or not, it is a matter of no small wonder that the commutation curves have not been more often obtained by designers.

Last year the writer carried out some investigations with a view to recording by means of the oscillograph the actual manner in which the current is reversed during commutation, and he has pleasure in presenting the results to this meeting.

The figures with which the writer illustrates this paper are records, taken with a Duddell pattern oscillograph, of the actual current in one particular coil on the armature of a shunt-wound motor.

The machine tested was a small four-pole Westinghouse rotary converter, which was used as a 6 H.P. shunt motor running at

1,200 r.p.m. on a 110 volt circuit. The motor has four brush arms, with one carbon brush, $1\frac{3}{8}$ inch × $\frac{1}{2}$ inch thick per arm; the commutator surface running with direction of slope of the brushes. Each commutator segment is 10 mm. wide with 0·5 mm. insulation, and the

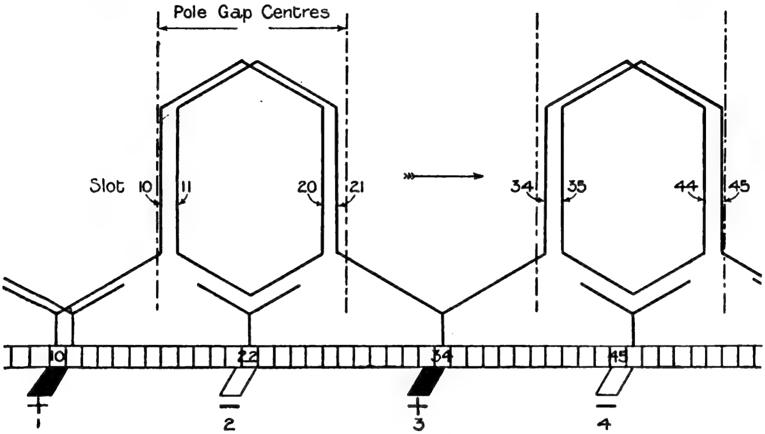

FIG. 1.

brush covers 1·21 segments. Owing to the machine having heavy copper damping rings on the poles, the light load input is considerable. These rings also effect the flux distribution.

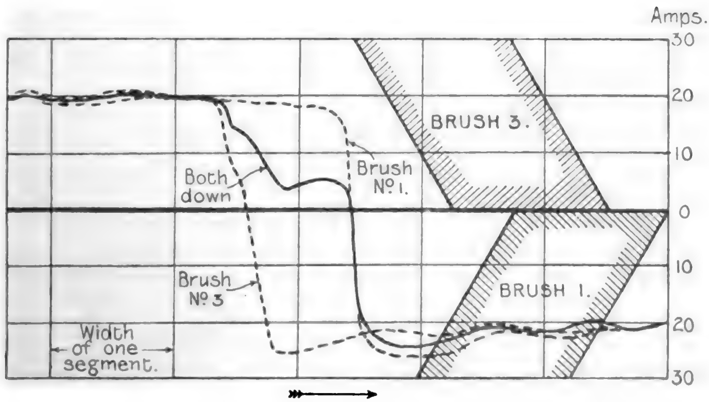

FIG. 2.

The output was measured by means of a brake on the pulley, and as far as possible observations were made at full load; but the time taken in recording the shape of the commutation curve in the brush-shifting experiments, the burning up of the brake band and the

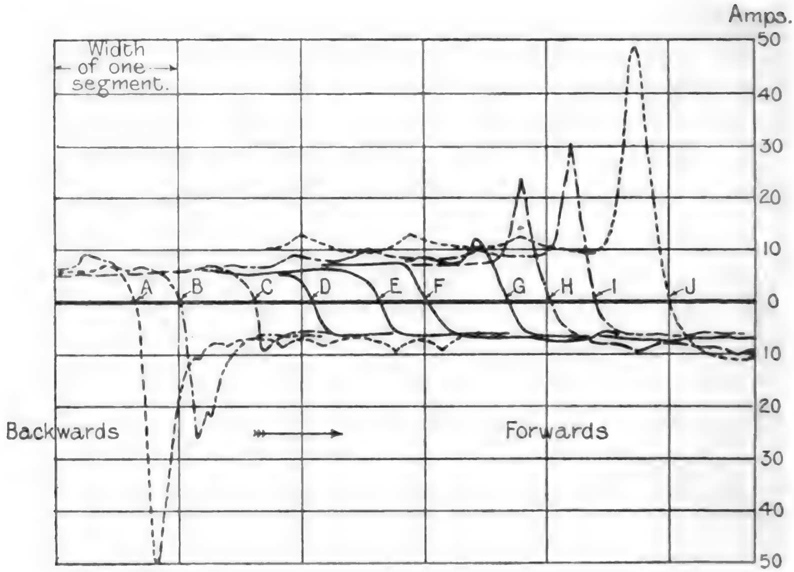
Amps.
50
40
30
20
10
0
10
20
30
40
50
Width of one segment.
A
B
C
D
E
F
G
H
I
J
Backwards
Forwards

FIG. 3.

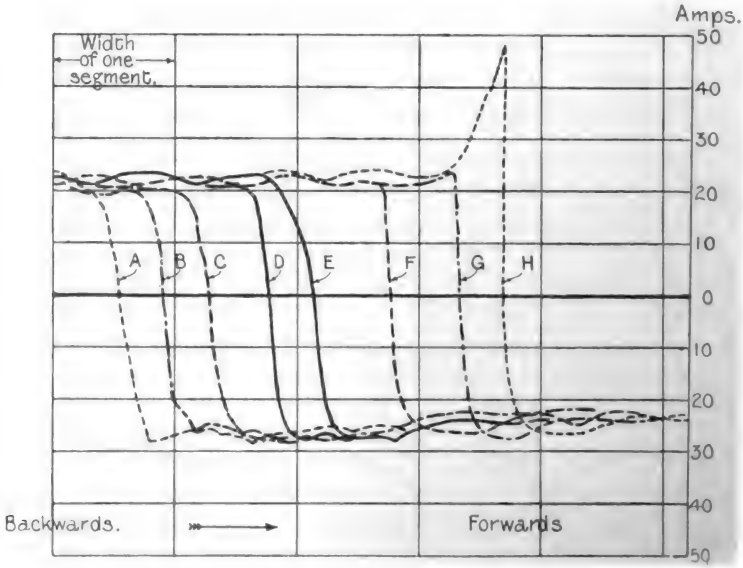
Amps.
50
40
30
20
10
0
10
20
30
40
50
Width of one segment.
A
B
C
D
E
F
G
H
Backwards.
Forwards

FIG. 4.

excessive sparking on the commutator, made it imperative to work at half load. The method used for observing the current in the coil was as follows. The armature circuit was cut at a point remote from the commutator, and the two ends of the coil thus exposed were connected to a pair of slip rings, the brushes on these rings being joined together by a strip of manganin sufficient to give about ¼ to ½ volt "drop" at full load, the oscillograph was connected across this strip and thereby showed the current in that particular coil at any instant. The ordinary type of Duddell oscillograph is arranged to show one and a half cycles of a periodic current, with the result that commutation is shown as being practically instantaneous; but by fitting a special cam on the motor which would produce a complete oscillation of the vibrating mirror in the time taken by five commutator segments in passing a brush the part of the curve showing the reversal is magnified to a useful size; in these experiments the horizontal magnification is about eight times that due to the ordinary cam.

Fig. 1 shows the armature circuit, this being a four-pole wave winding of the chord type. With this type of winding the four sides of the two coils do not arrive at the geometrical neutral point at the

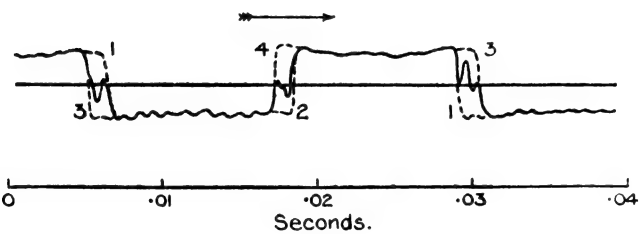

Fig. 5.

same instant, and if four brushes are used, this, as will be shown later, causes a considerable circulation of current between the two brushes of the same polarity; the circuit consisting of the armature coil, between the two brushes, the brushes themselves, and the brush connectors. This occurs, to some extent, in all wave windings where there are as many brush arms as poles, and involves a heating loss. There are 47 commutator segments; and, as the brush rocker is symmetrical, one brush starts commutating half a segment before the other brush of the same polarity. This is shown in Fig. 2, which is a record of the commutation curves with the brushes at the geometrical centre, for brush No. 3 alone, No. 1 alone, and both down (1 and 3 are of the same polarity). The load was 3·6 B.H.P. at 1,200 revolutions per minute with slight sparking in each case. The brush density is 65 amperes per sq. inch with one, and 32½ amperes per sq. inch with two positive brushes. This figure also shows the width of a segment and a brush, which is the same for Figs. 2, 3, 4, 8 and 9.

When the two positive brushes are down, the interval during which the current in a given coil has to be completely reversed, is

prolonged, and as is seen in Fig. 2 the current dies away more slowly, so that the conditions for sparkless commutation are better.

Figs. 3 and 4 were taken with only two brushes down, viz., one brush of each polarity—brush No. 2 and No. 3. They show the commutation curves at light load and at 60 per cent. of full load with forward and backward lead of various amounts given to the brushes.

The following table gives the lead of the brushes for the various curves in Figs. 3 and 4 :—

Curve.	Lead.	
	Fig. 3.	Fig. 4.
A	2 segments backward ...	$1\frac{3}{4}$ segments backward
B	$1\frac{1}{2}$ " " ...	$1\frac{1}{2}$ " "
C	1 " " ...	1 " "
D	$\frac{1}{2}$ " " ...	$\frac{1}{2}$ " "
E	0 geometrical neutral point	0 geometrical neutral
F	$\frac{1}{2}$ segments forward ...	$\frac{1}{2}$ segments forward
G	$\frac{1}{2}$ " " ...	1 " "
H	2 " " ...	$1\frac{1}{2}$ " "
I	$2\frac{1}{2}$ " " ...	
J	$2\frac{3}{4}$ " " ...	
B.H.P.	Light	3·6
Brush density	20 amperes per sq. inch ...	65 amperes per sq. inch

There was excessive sparking at both limits, and practically none at the neutral point.

The peaks in the current which occur when the brushes have a big lead are not steady, there being a considerable variation of amplitude, and the pulsations occurring with the fierce sparks on the commutator.

Fig. 5 is a record taken with the ordinary cam on the synchronous motor, and shows the alteration of the shape of the armature-current curve when each brush is lifted in turn. It will be seen that the length of the wave varies according to which brush is lifted. The reason for this is clearly explained by Fig. 6, which shows diagrammatically by a full line the current curve with brushes No. 2 and No. 3 down, and by a dotted line with brushes No. 1 and No. 4 down. When both positive brushes are down, the curve falls between these limits, as can be seen in Figs. 2 and 5. The current taken by the motor is of course unaffected by these alterations in the lengths of the current waves, because the other armature circuit has exactly similar waves in it.

Fig. 7 is a set of oscillograms taken with all four brushes down, and shows the commutation curve at light load and full load for each brush. The brushes were fixed at the geometrical neutral position ; there was slight sparking at Nos. 1 and 5. The load was 6·0 B.H.P. at 1,200 revolutions, and the brush density 48 amperes per sq. inch.

It must here be noted that the relative horizontal position of the light load and full load curves in the figures is quite arbitrary, and for convenience they are placed cutting the zero line together. If at light

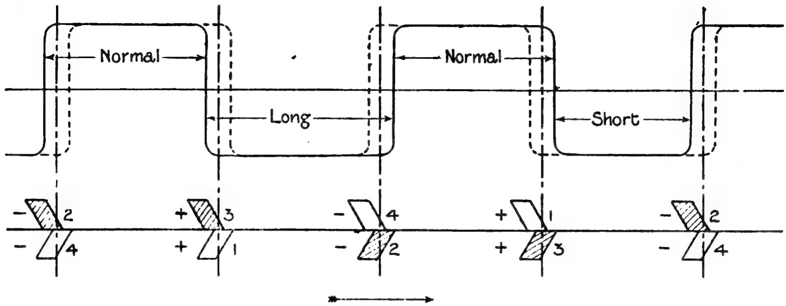

FIG. 6.

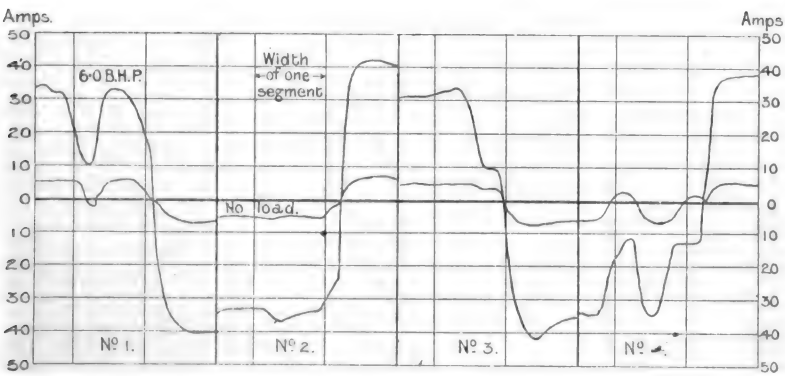

FIG. 7.

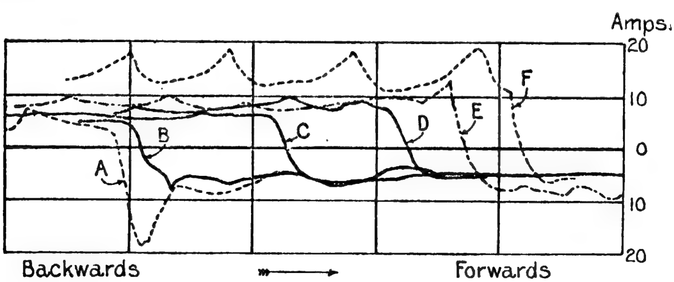

FIG. 8.

load a curve is taken, and the load is increased, the curve expands vertically, and also moves horizontally. This horizontal movement is made up of (1) the change of shape of the curve itself with load, and

(2) the alteration of the phase of the synchronous motor due to the armature reaction in the shunt motor.

Figs. 8 and 9 show the curves of commutation with four brushes instead of two. The heavy circulating current between the two brushes of the same polarity are shown in these curves as well as in Fig. 7. On referring to Figs. 3 and 4 it will be noticed that, with two brushes only, the circulating currents do not occur. When the brushes are in extreme positions the effect of the armature teeth is very marked; this may be compared with the armature current-curves published by Dr. D. K. Morris and the writer in January, 1904.*

The following table gives the lead with which the various curves were obtained, also the motor input :—

Curve.	Lead.		Lead.	
	Fig. 8.	Motor Current.	Fig. 9.	Motor Current.
A	1½ segs. backward	20 amps.	1½ segs. backward	57 amps.
B	1 " "	17 "	1 " "	55 "
C	0 geo. neutral joint	16 "	½ " "	53 "
D	1 segs. forward	16½ "	½ " forward	52½ "
E	1½ " "	18 "	1 " "	54½ "
F	2 " "	23 "	1½ " "	57 "
B.H.P.	Light.		3·6	
Brush density	9·9 amps. per sq. inch.		33 amps. per sq. inch.	

These curves show very clearly the desirability of using as narrow a brush as possible on a motor with a large polar arc in which the neutral zone is small. A wide brush soon has one or other edge in contact with conductors in a comparatively strong field, which will certainly produce heavy short-circuit currents.

In Fig. 10 the input of the motor is plotted against the lead of the brushes, for light load and half load, with four brushes down, and gives some idea of the increased loss which results through wrong brush position. This loss goes in increased heating of the armature and commutator.

In most modern motors the pole arc is between 65 and 75 per cent. of the pole pitch, depending upon the length of the air-gap and the chamfer of the pole shoes. The neutral zone is therefore very limited. The effect of this is to necessitate narrow brushes and at the same time to prevent much movement of the neutral position between no load and full load.

The calculation of the "reactance voltage" of a coil undergoing short circuit is now usual in designing a continuous-current motor ; and the

* *Journal Institution Electrical Engineers*, 1904, Part 168, Vol. 33.

method most often adopted is that proposed by Mr. Hobart. The change of current in the armature coil during the commutation interval is assumed to follow a sine law, the reactance voltage then being

$$2\,\pi\,n\,\mathrm{L}\,\mathrm{C}$$

when n = the equivalent frequency of commutation

and $= \dfrac{\text{Peripheral speed of commutator}}{2 \times \text{Brush thickness}}$.

L = the inductance of the coil, in henrys.

C = the current in the coil.

The usual method of calculating "L" for normal slotted armatures is to assume that a conductor embedded in a slot has 4·0 lines per cm. linked with it per ampere, and that the free length, *i.e.*, the end connections, have 0·8 lines per cm. per ampere. These figures are the result of tests by Mr. Hobart and apply to slots, with a ratio of depth to width of about 3 to 1.

In the case of the four-pole wave winding with four brushes down, it is evident that there are two paths by which a coil is short-circuited during commutation :—

(1) By two brushes and their connector.
(2) By two coils in series, and the brush bridging the two adjoining segments.

When only two brushes are used the first case cannot occur.

Calculation of Reactance Voltage.

Peripheral speed of commutator, inches per second		=	390
Thickness of brush, inches		=	0·5
Frequency of commutation, cycles per second ...	(n)	=	390
Width of segment (including insulation), mms. ...		=	10·5
Maximum number of coils, short-circuited under a brush		=	2
Turns per coil	(q)	=	2
Maximum number of simultaneously commutated conductors per group	(r)	=	8
"Free length" per turn, cms.	(s)	=	41
"Embedded length" per turn, cms.	(t)	=	32
Lines per ampere-turn per cm. of "free length" ...	(u)	=	0·8
Lines per ampere-turn per cm. of "embedded length"	(v)	=	4·0
Lines per ampere for "free length" $\left(\frac{r \times u \times s}{2}\right)$ ...	(o)	=	131
Lines per ampere for "embedded length" ($r \times v \times t$)	(p)	=	1,024
Total lines linked with short-circuited coil per amp.	($o + p$)	=	1,155
Inductance per segment $q\,(o + p)\,10^{-8}$, henrys ...	(L)	=	·0000231
Reactance per segment $2\,\pi\,n$ L		=	·0567
Current at full load per circuit $\left(\frac{78}{2}\right)$, amperes ...	(C)	=	39
Full load "*Reactance Voltage,*" volts		=	2·2

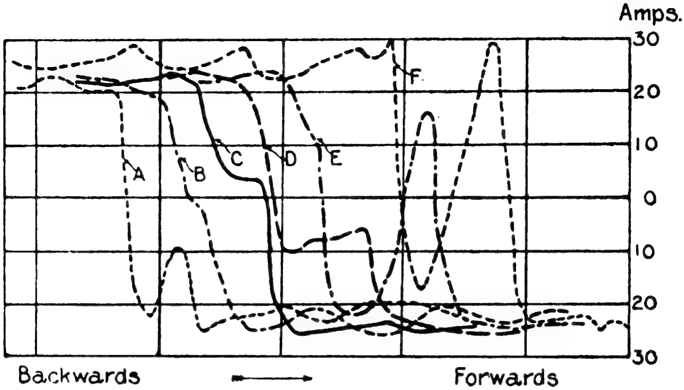
Amps.
30
20
10
0
10
20
30
A
B
C
D
E
F
Backwards
Forwards

FIG. 9.

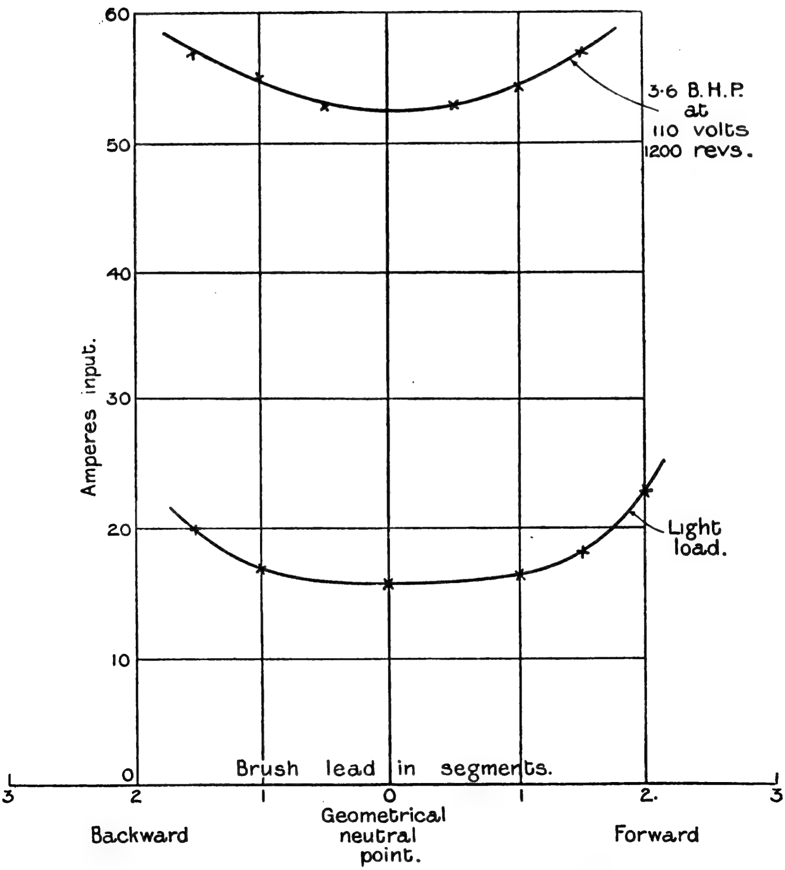
60
50
40
30
20
10
0
Amperes input.
3·6 B.H.P.
at
110 volts
1200 revs.
Light
load.
Brush lead in segments.
3
2
1
0
1
2.
3
Backward
Geometrical
neutral
point.
Forward

FIG. 10.

This figure, 2·2 volts, is the minimum sparking figure, being due to one coil only. The worst case is with two brushes only when the voltage becomes 4·4. If four brushes are down, the voltage is probably between these two values.

The preceding commutation curves show that in all probability the sine curve is rarely to be met with, and that the method of calculating the reactance voltage gives little more than a guiding figure; however, as a guide, this figure is very useful, especially in the comparison of similar types of machines.

Undoubtedly the best practice is to design a machine with its reactance voltage less than the brush drop whenever possible especially with reversible motors having a fixed brush position.

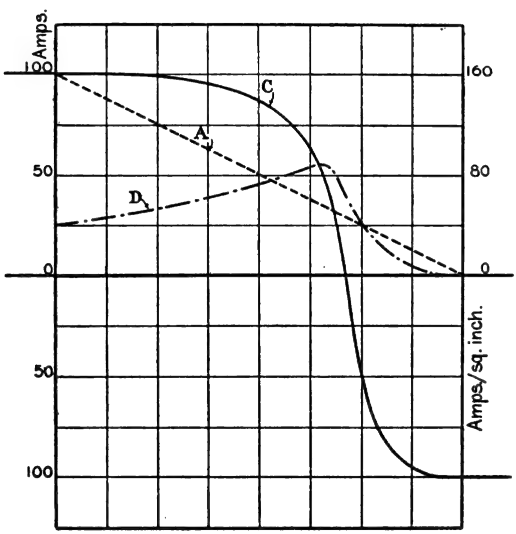

FIG. 11.

It is permissible to work with a higher value of reactance voltage on small than on large machines; on the other hand it is generally possible, without much trouble, to keep the figure down on small machines, whereas large machines work more nearly at the maximum value allowable. Small machines with stiff fields are usually designed with a reactance voltage of about 2·0, although 4·0 volts will usually be satisfactory. With large machines it is difficult to keep the figure below 3·5 to 3·0 volts. With variable speed motors, etc., which have to work with fixed brush position and weak fields, there is no reversing field to help commutation, and the reactance voltage must be kept below 1·0 to 1·5 volts. These figures, of course, do not apply to machines with special commutation poles, in which the existence of a definite and fixed reversing field simplifies commutation immensely, and allows of three or four times the values given above.

In dealing with the problem of sparkless commutation, we are chiefly interested in what is occurring while a segment is leaving the brush, and the part played by the self-induction of the coil. The effect of the self-induction of the short-circuited armature coil is first to prevent the current in the coil dying away quickly, and then to retard the growth of the current from the other side of the armature, tending to a continuation of the current in the rapidly diminishing contract-area of the brush and retreating segment. It is thus seen that the inductance of the coil causes the current density in the brush tip to rise to high values, as is shown diagrammatically in Figs. 11 and 12, C being the current commutation curve, A the contact area between the retreating

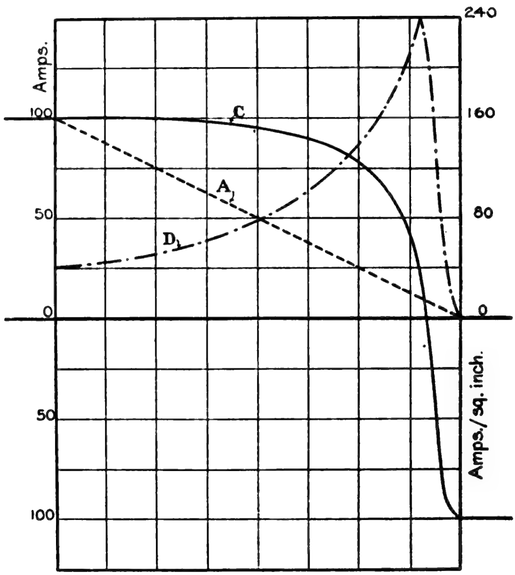

FIG. 12.

segment and the brush (thickness equal to one segment), and D the current density in the brush tip. The preceding oscillograms show that the current curve is usually very late in reversing, and consequently the current density reaches very high values, rendering the brush tip very hot, sometimes incandescent, with resulting disintegration and sparking. The limit to the permissible density depends upon the shape of the curve, *i.e.*, how long the high density lasts in comparison to the interval of short circuit. It seems to the writer that with a curve similar to Fig. 12 the peak should not exceed about 300 amperes per square inch with ordinary carbon brushes. Experiments upon this point should be of great value. Fig. 11 is a typical case in which conditions obtain suitable for sparkless commutation, the brush density curve being flat. Fig. 12 shows the effect of increased self-induction in the coil, the reversal being late and the current density rising from

40 amperes per square inch to 240 amperes per square inch. It will be noticed that for nearly half the time the density exceeds 100 amperes per square inch.

From the above it is clear that the question of current density in the brush tip is of first importance, to neglect the consideration of which is as if a gas-engineer designed his cylinders to withstand the mean pressure of the explosion, instead of the maximum pressure.

Before concluding, the writer wishes to express his thanks to Mr. G. A. Lister, of the Birmingham University, for his help during the tests referred to in this paper.

Mr. H. M. HOBART (*communicated*): I find in the author's paper a most valuable investigation of the occurrences at commutation, by means of the oscillograph. The agreement between the oscillograph records and the results shown in Fig. 10 for the test of amperes input with varying brush leads is most interesting. I have published a hypothetical curve corresponding to the lower curve of Fig. 10, at a venture, in July, 1902 (*Traction and Transmission*, vol. 4, p. 140, Fig. 24), and I suggested that such tests would give us information of great value. I am surprised to see that the curves of Fig. 10 are symmetrical on both sides of the neutral point. It would be interesting to know whether this would still be the case at higher loads. Similar tests with various grades of brushes would be replete with interest, and also tests with a given grade of brush, but with various thicknesses. A thorough investigation of various qualities and widths of brushes by means of the oscillograph might lead to some better criterion of commutation than the "reactance voltage," which, while it is useful pending the appearance of a truer guide, could undoubtedly be superseded to advantage. Mr. Hobart.

Mr. C. C. HAWKINS (*communicated*): I should like to draw attention to the necessity for a great many more experimental determinations than have yet been made of what is the apparent inductance of armature coils upon which commutation depends. Such experiments are sadly wanted in order to check the results of calculation, and must be carried out under strictly defined conditions. The armature should be in place within its field, and the field-windings should be closed upon the armature winding, and further the magnet should be fully excited. Too often one or other of these conditions have been overlooked; yet they are of great importance, since in actual working the damping action of the field-magnet and its poles, especially when solid, causes the apparent inductance, which affects commutation, to be much less than the true inductance. While recognising to the full the importance of the attention which has been directed by Messrs. Parshall and Hobart to the so-called "reactance voltage" of the coil undergoing short-circuit, I cannot but regard it as most unfortunate that the underlying idea has become involved with a sine-wave assumption. Reactance is a relation purely dependent upon a sine-wave rate of change. Such a condition never occurs in practice, and is indeed entirely opposed to the facts. As we do not know the real $\frac{di}{dt}$ Mr. Hawkins.

Mr. Hawkins.

in default of an oscillogram such as those of the paper, why do not we confess our ignorance and remain content with the expression $(L + \Sigma M)\frac{2J}{T}$ as a guide to the "inductive voltage"?—where

$L =$ The self-induction of the coil.
$\Sigma M =$ The sum of all the coefficients of mutual induction in the simultaneously short-circuited coils.
$J =$ Current per armature section.
$T =$ The entire time of short-circuit.

The author is fully alive to the fact that the sine hypothesis is far removed from the truth, and recognises that we can only obtain a "guiding figure." Of course the above expression is in exactly the same way only a guiding figure, being $\frac{2}{\pi}$ of the "reactance voltage"; but as it simply takes the average rate of change of the current, it is free from any assumption, and the actual form factor may be left to be added when further experience has been accumulated. In the calculation of the $L + \Sigma M$, I believe that Mr. Catterson-Smith has assigned too great an effect to the core inductance in his particular case; its amount being estimated as 0·0000205 out of a total of 0·0000231 henry. Different proportions of slot and different distributions of winding cause the inductance to vary so very widely, that it is safer to make even an approximate calculation of each component rather than to rely on an assumed figure of four lines per cm. and per ampere. An attempt at a fuller analysis of the various components of the inductance has been published by me in the *Electrical World and Engineer*, vol. xlii., the object being to give a method for calculation on a definite system, so that the results should be strictly comparable. To check such a system, the experiments to which I have just alluded are required.

The distribution of the short-circuited wires in a pair of interpolar gaps would be as shown in the sketch, where the considered section

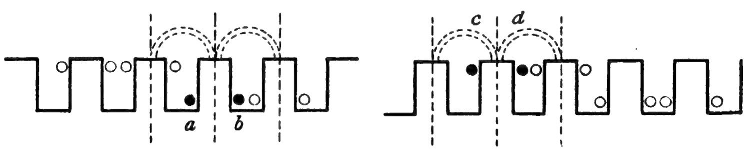

FIG. E.

is marked black. The case of a coil-side divided between two slots is not dealt with in the above-mentioned articles, but on the same principles as therein given, the slot inductance, self and mutual, works out as follows:—

(*a*)	$11{\cdot}52 \times \frac{\text{depth of slot}}{\text{width of slot}}$	$\times$ length of core	$\times$	10^{-9}		
(*b*)	16·77	”	”	”	”	
(*c*)	2·09	”	”	”	”	
(*d*)	4·19	”	”	”	”	
Total	$34{\cdot}57 \times 4{\cdot}06 \times 16 \times 10^{-9} = 0{\cdot}00000224$ henry.					

This assumes that the wires come right up to the top of the slots, and would require a little alteration if there were wooden wedges at the top, the ratio of depth of slot to width in the above being reduced, but a further item being required for the flux that crosses the top of each slot. Mr. Hawkins.

Owing to the stretch of core occupied by the wires being nearly equal to the width of an interpolar gap, and on the assumption that all variation of the flux entering the pole-tips is damped out therein, the inductance from the surface of the core will be only that due to small local groups of lines arching over the tips of the slots in which lie the wires of the considered section as shown, and it can be estimated to be 0·00000059. The total core inductance will thus be approximately 0·00000283, or only about 14 per cent. of that obtained on the assumption of 4 lines per cm. and per ampere. This great difference is to be traced to the chord-winding, to the subdivision of each coil-side between two slots, and to the wide extent of the short-circuited wires as compared with the interpolar gap. If T be the time of short-circuit as reckoned from the width of the brush, the real time of short-circuit in a wave-wound armature with as many sets of brushes as there are poles is $T\left(1 + \frac{X}{y}\right)$, where X is the fraction of a sector which results from number of sectors ÷ number of pairs of poles, and y is the width of a brush expressed in terms of the width of the sector. In the case mentioned in the paper, with four sets of brushes, the time of short-circuit becomes extended from 0·00123 second to 0·00123 (1·417) = 0·00174 second. For part of this time it is evident that short-circuit is occurring through the leads which connect the brushes of similar sign, so that if the commutation of a single section in a wave-wound armature is treated as above on the same lines as that of a lap section, a more conservative figure must be allowed for the limit which the inductive voltage might reach.

Professor R. THRELFALL: I hope that the results obtained will assist designers in producing machines that may be depended upon not to spark. Proper commutation is most important, and is absolutely essential in cases where machines have to run continuously. I have often had machines which ran very well for a short time, but which began to spark when thoroughly heated. I believe that freedom from sparking in machines is obtained by the careful design of small details, rather than by any special feature. Professor Threlfall.

Mr. W. BREW: I have had to deal with many sparking troubles. Two large two-pole machines had developed flats on the commutator. The cause was traced to the lifting of the armature every time the cranks arrived at the dead centre, causing the brushes to jump. This was got over by raising the magnets so that the magnetic reluctance on the top side of the armature was increased, while that on the lower side was reduced. The connections were also altered, so that the point of commutation was not effected by the dead centres. Another case was that of two machines driven tandem, in which the armatures were not magnetically in a correct position on the field. At some loads this Mr. Brew.

Mr. Brew. resulted in a violent oscillation of the shaft, which had a bad effect on the commutator.

Mr. Forster. Mr. A. L. FORSTER : Could the author give us any information as to where the commutation line cut the zero in relation to the brush? Were any measurements taken of the currents in the cross connections, and and if so, was this current steady?

Mr. Marples. Mr. E. MARPLES : Two instances have come under my notice where bad sparking occurred in four-pole machines having two brushes only. In each case the trouble has been overcome by using four brushes. The author in his paper clearly shows the reason for this.

Mr. Catterson-Smith. Mr. J. K. CATTERSON-SMITH (*in reply*) : I cannot fix the position of the neutral point with regard to the curves. In the machine I used for my experiments, the poles were not quite central magnetically, which caused a slight want of symmetry. I did not at the time measure the current in the leads connecting similar brushes, but this has since been done, and the current has been found to be steady.

I agree with Mr. Hawkins as to the advisability of determining the self-induction of armature coils under standard conditions. I cannot understand in what way Mr. Hawkins' "inductive voltage" is any more free from an assumption than Mr. Hobart's "reactance voltage." Mr. Hawkins calculates the average rate of change of current which assumes a "straight line," while Mr. Hobart assumes a "sine" law. I am interested in the method employed by Mr. Hawkins for calculating the self-induction, and think it should give a much more reliable figure than the rough approximation given in the paper. Most manufacturers have their own particular sparking criterion, mostly based upon the various works of Messrs. Hawkins, Arnold, and Hobart. I should like to point out that in calculating the electromotive forces acting during commutation, it should be noticed that the drop between the brush and segment is nearly constant until very high densities are reached, whereas most writers assume that it is proportional to the contact area as the segment leaves the brush.

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BIRMINGHAM LOCAL SECTION.

THE EDDY CURRENT BRAKE FOR TESTING MOTORS.

By D. K. MORRIS, Ph.D., and G. A. LISTER, Associate Members.

(*Paper read April* 12, 1905.)

SYNOPSIS.—Introduction: Methods of motor testing in use—Advantages of eddy current brakes—New design of eddy current brake—Detailed description—Experimental results obtained—Working of the brake—Theory of the eddy current brake—Application of theory to design of eddy current brakes—Conclusion.

INTRODUCTION: METHODS OF MOTOR-TESTING IN USE.

The testing of a motor for efficiency and suitable rating requires that the motor shall be subjected for short or long periods to a measured load of any desired amount. Steady maintenance and accurate measurement of the load are necessary; while the means of applying it should in no way affect the conditions under which the motor works.

It is interesting to review the methods of motor-testing which have been proposed; and, generally, to consider the possible methods of absorbing and measuring the energy of a motor. They group themselves naturally as in Table I. according to the nature of the device employed, whether mechanical, hydraulic, or electrical; and to the method of absorbing the energy, whether the latter is or may be utilised, or whether it is immediately dissipated. In Professor Threlfall's calorimetric method the motor output is not measured directly, but is derived from the input by subtracting the measured losses.

Transmission dynamometer methods are properly applicable only to the testing of generators; while the "slowing down" method of Dr. Sumpner, not being one in which the motor is continually loaded, is not classed in the table.

TABLE I.—METHODS OF MOTOR-TESTING.

<table>
<tr><th>Nature of energy-absorbing Apparatus.</th><th colspan="2">(1) Energy Utilised.</th><th>(2) Energy Dissipated (Absorption Brakes).</th></tr>
<tr><td>Mechanical.</td><td colspan="2">Lifting weights :—
e.g. in determining combined efficiency of cranes or hauling gear.</td><td>(a) Block (Prony, etc.).
(b) Rope.
(c) Band (Soames, etc.).</td></tr>
<tr><td>Fluid.</td><td colspan="2">Pumping :—
e.g. in determining combined efficiency of motor pumps.</td><td>(a) Water (Froude).
(b) Air friction.</td></tr>
<tr><td rowspan="4">Electric.</td><td colspan="2">(a) Load taken up in separate generator of known efficiency.
(b) "Hopkinson" methods as below.</td><td rowspan="4">(a) Eddy currents only.
(1) Fixed field.
(2) Revolving field.
(b) Eddy currents and hysteresis.
(1) Fixed field.
(2) Revolving field.</td></tr>
<tr><td colspan="2">Losses supplied.</td></tr>
<tr><td>Mechanically.</td><td>Electrically.</td></tr>
<tr><td>By belt.
By direct-coupled motor.</td><td>Parallel system.
Series system.</td></tr>
</table>

The electrical methods in which the energy is immediately dissipated may be classified in this way :—

TABLE II.—ELECTRIC TESTING BRAKES.*

	Eddy Currents only.	Eddy Currents and Hysteresis.
Fixed field.	(a) Air-cooled. (Pasqualini, 1892. Grau, 1900. Siemens & Halske.) (b) Water-cooled.	(a) Air-cooled (Rieter, 1897). (b) Water-cooled.
Revolving field.	(a) Air-cooled. (b) Water-cooled.	(a) Air-cooled (Rieter). (b) Water-cooled (Körting).

* Pasqualini, *Fortschritte der Physik*, 1892, p. 421 ; A. Grau, *Elektrotechnische Zeitschrift*, 1900, p. 265, and 1902, p. 467 ; E. H. Rieter, *Elektrotechnische Zeitschrift*, 1901, p. 195 ; K. Feussner, *Elektrotechnische Zeitschrift*, 1901, p. 608 ; Siemens and Halske, *Nachrichten*, 1902, No. 32 ; Brion, *Elektrotechnische Zeitschrift*, 1905, p. 83.

In all the above eddy current brakes, the revolving portion only is carried by the motor spindle, the fixed portion being supported on either circular or knife-edge bearings.

The opportunities of applying methods in which the energy may be utilised are few. For, of these, mechanical and fluid methods are out of the question for general testing, and electrical methods necessitate the use of auxiliary machinery.

Again, to test a motor by coupling it either directly or by belt to a generator of known efficiency is at the best but an indirect proceeding. Any variation of the conditions as regards speed, temperature, or state of bearings will alter the generator efficiency, and there is always a small, and usually unknown, loss in belt driving. The "Hopkinson" method in its various forms requires two exactly similar machines. Where these are available, this method has no rival, unless in the case of small machines for which the parallel Hopkinson test may require abnormal conditions of running.

Of the class in which the energy is dissipated, air friction brakes are cumbrous, while the water brake is expensive in construction and ill-suited for testing small motors, although excellent for large powers. Mechanical and eddy current brakes are much superior for ordinary testing.

Advantages of Eddy Current Brakes.

The eddy current brake has many advantages over the band or rope methods of motor-testing. Among these are :—

(*a*) Sensitiveness combined with convenience of adjustment to exact balance.

(*b*) Uniformity of load, and exact constancy after final temperature conditions have been reached.

(*c*) Heat produced in energy-absorbing element not conducted to bearing.

(*d*) Absence of wear.

(*e*) Retarding torque only occurs.

The first three arise from the nature of the friction employed, and from the simplicity and fineness of rheostatic control. The advantage referred to in (*c*) is one of great importance. The continual stream of air outwards past the copper disc, carries away the heat in a remarkable manner, so that the copper disc may be very hot indeed for long periods, while the adjacent bearing remains quite cold. The nature of the stresses, too, permits of a relatively perfect thermal isolation of the disc as compared with a pulley rim.

Methods based upon mechanical friction demand water-cooling where *time* tests have to be made on motors above 1 or 2 H.P. With specially large pulleys, this limit can of course be raised. No such limit exists with the eddy current brake. With such apparatus, correctly designed, the absorption capacity appears to be determined only by the heating of the magnetising coils.

The mechanical forms of brake combine great simplicity with considerable sensitiveness; but the advantages enumerated above have

sufficed to direct attention to the construction of the eddy current brake, several patterns having been produced.

New Design of Eddy Current Brake.

The types of eddy brake on the market, however, have not been very widely used, mainly on account of the high initial cost, and the difficulty of applying them to various sizes and types of motors.

They are constructed on one of the following principles :—

(1) The revolving element is secured to a spindle, one end of which is coupled to, or belt-driven from, the motor shaft. This brake-spindle revolves in bearings carried by an independent frame, which also carries by means of ball-bearings the floating portion of the brake.

(2) The revolving element is secured direct to the motor-shaft, the fixed portion being provided with knife edges, and mounted on a separate frame.

In the former case a correction of an uncertain nature arises on account of the friction of the bearings, and probably on account of air-friction, while in the latter either the brake or the motor has to be specially mounted, that the centres may be brought approximately into line. In such brakes, also, end-play should be minimised.

To surmount these difficulties the authors, in designing a brake for the Electrical Laboratory of the University of Birmingham, decided to entirely dispense with separate bearings or frame. This brake is illustrated in Fig. 1. It is intended to be mounted on the motor-shaft in place of the ordinary pulley. The fixed portion of the brake is carried by the revolving system, and though there is friction at the bushes, B and D, this small load is duly represented as torque on the brake-lever. A similar argument applies to the air friction.

Mechanical and electrical symmetry are insured by the use of two copper discs, one revolving on either side of the magnetising coils. This doubles the capacity of the brake for a given diameter and, incidentally, renders it completely astatic. A multi-polar design was employed, since in this case the weight is less than that for a two-polar design.

Fig. 2 shows the brake mounted on the spindle of an electric motor, and indicates the manner in which the pressure on the motor-bearing may be adjusted. The brake is provided with a link suspension, so that an upward pull gives rise to no twisting moment. This suspension is attached to a spring balance, which can conveniently be carried by the hook of the crane or blocks serving the testing bed. By means of the lifting gear the pressure on the bearing may be reduced to nothing, or it can be given any desired value. Bearing friction in motors may be tested with this brake with an accuracy not hitherto possible.

In cases where lifting gear is not available, the suspension and balance could be carried by a special frame, provided with screw and hand-wheel. For ordinary testing the whole brake can very well be carried on the motor-spindle without suspension, since its weight is less than the normal belt-pull.

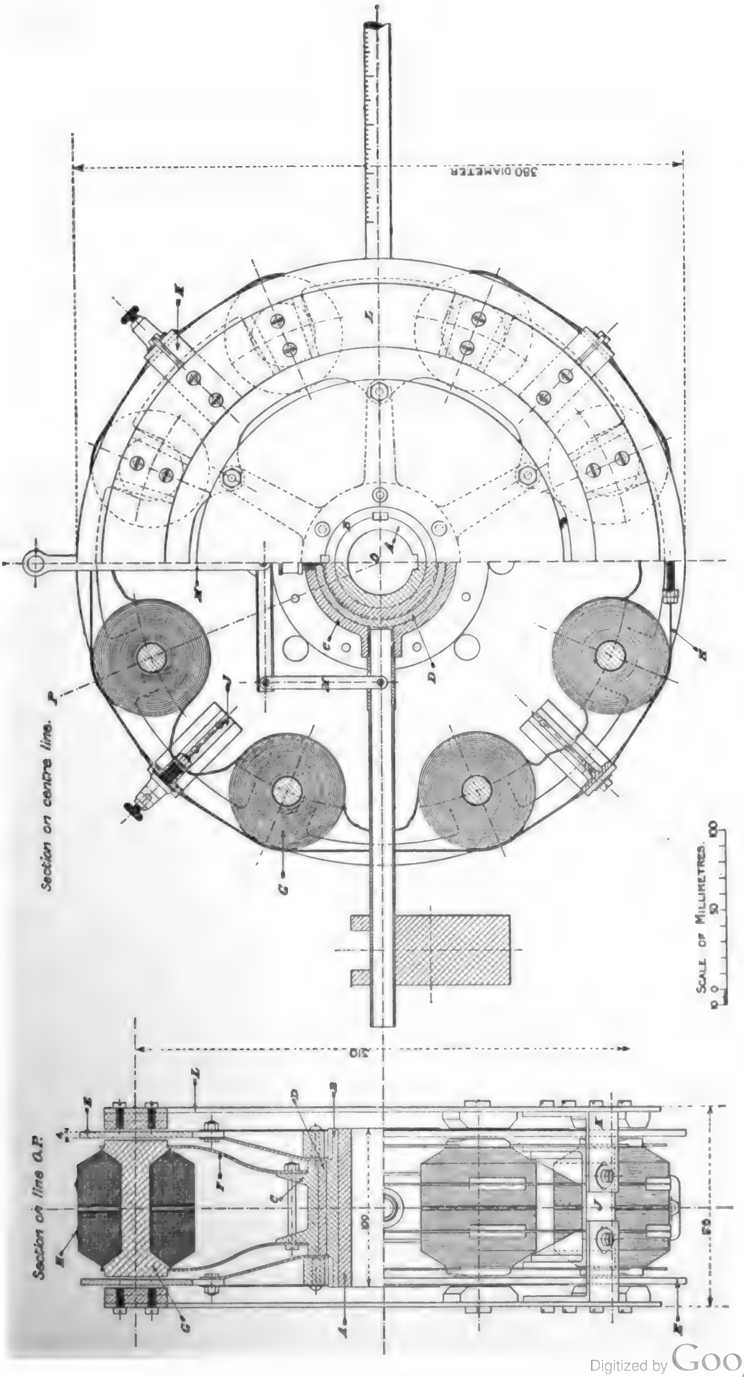


FIG. 1.—Motor Testing Brake—Eddy Current Type. For Motors up to 5 B.H.P. at 1,000 R.P.M., or $7\frac{1}{2}$ B.H.P. at 1,750 R.P.M., with overload capacity of 25 per cent. in each case.

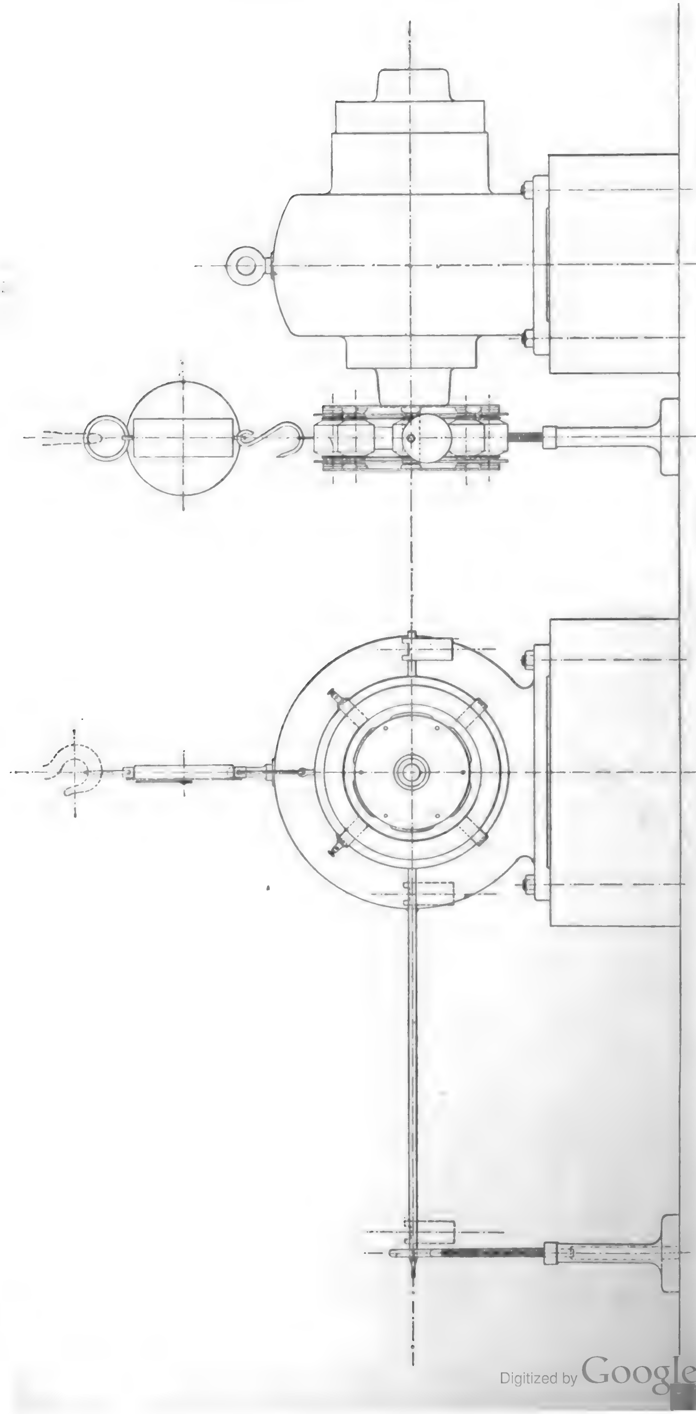


FIG. 2.—Motor Testing Brake—Eddy Current Type.

The construction described has therefore the following additional advantages without in any way sacrificing those enumerated on p. 447.

(*f*) Apparatus self-contained; no separate frame required; an advantage over all other practical types of brake.

(*g*) Brake is completely astatic.

(*h*) Air-friction error is practically eliminated.

(*i*) Pressure on motor-bearing during test may be adjusted to any desired amount, independent of the load.

Detailed Description.

The revolving discs, E, are made of high conductivity hard-rolled copper. They are supported by a thin steel plate and steel arms on the outer and inner sides respectively, each hub being keyed to the bush, B.

Between these discs is the casting, C, which is fitted with a gun-metal bush, D, bored to suit the bush, B. Into this casting are screwed two tubes, the shorter carrying the counterpoise, and the longer constituting the lever arm. This arm is marked with a scale of feet divided into tenths and hundredths of a foot, the maximum leverage being 3 ft. The brass plates, F, are bolted to the casting, C, and carry at their circumference the magnet coils, G. These coils, which are eight in number, are securely held in position by the steel wires, H. Each consists of a wrought-iron core wound with 1,400 turns of No. 20 S.C.C. copper wire. The resistance of each coil is 5·1 ohms when cold. There is a ventilating duct at the middle of the coil.

The aluminium castings, J, act as distance pieces, the two upper ones being fitted with insulated terminals. Secured to these castings by set-pins are the aluminium castings, K, which carry the external yoke-rings, L. A slotted hole in the castings, K, allows the length of the external air-gap to be adjusted. The length of the internal air-gap is fixed, and in consequence of the rigidity and smooth running can be kept short.

Steel bushes, A, are turned to suit the inside of bush, B, into which they are keyed. They are bored out to various sizes to suit the spindles of the motors which have to be tested. The suspension links, M, are fitted to the graduated lever and to the counterpoise lever at equal distances from the centre. Accurately adjusted sliding-weights of 2½ lbs., 5 lbs., 7½ lbs., and 10 lbs. are used.

After completion the brake was supported on a central knife-edge, and the counterpoise lever loaded until an accurate balance was obtained.

Experimental Results Obtained.

1. A test to determine the result of reducing the number of magnets showed that the braking effect is practically proportional to the number of coils excited. The slight reduction observed was probably due to the increased length of the iron portion of the magnetic circuit. In other words, the braking effect appears to depend only on the

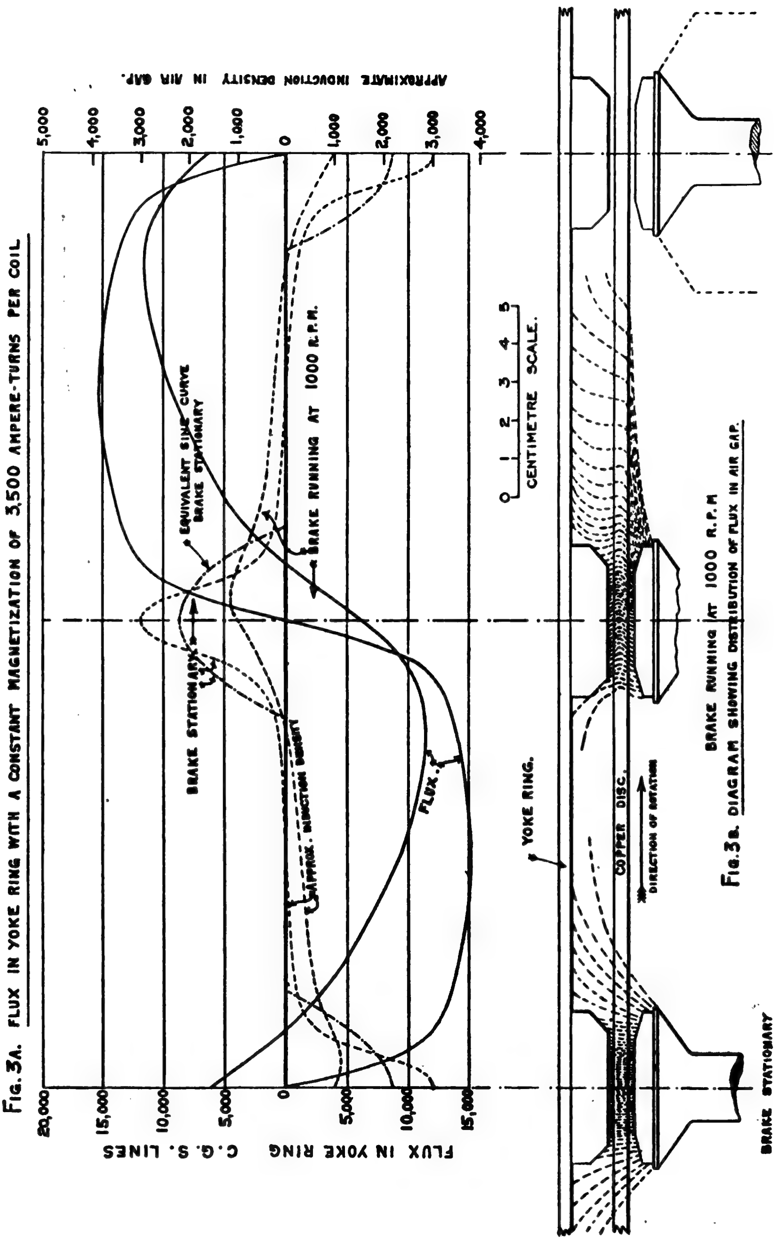


FIG. 3A. FLUX IN YOKE RING WITH A CONSTANT MAGNETIZATION OF 3,500 AMPERE-TURNS PER COIL
FLUX IN YOKE RING C.G.S. LINES
APPROXIMATE INDUCTION DENSITY IN AIR GAP.
EQUIVALENT SINE CURVE BRAKE STATIONARY
BRAKE RUNNING AT 1000 R.P.M.
BRAKE STATIONARY
APPROX. INDUCTION DENSITY
FLUX
CENTIMETRE SCALE.
YOKE RING.
COPPER DISC.
DIRECTION OF ROTATION
BRAKE STATIONARY
FIG. 3B. DIAGRAM SHOWING DISTRIBUTION OF FLUX IN AIR GAP.
BRAKE RUNNING AT 1000 R.P.M.

FIG. 3—A AND B.

total flux cutting the copper, and is independent of the number of points at which it may be applied.

2. The removal of the external yoke-rings resulted in a reduction of the absorption capacity to about 50 per cent. of the normal for a given number of ampere-turns per coil.

3. The torque produced by bearing and air-friction alone (the magnets being unexcited) was found to be about 0·3 ft.-lbs. at 500 r.p.m. This increased to 0·365 ft.-lbs. at 1,250 r.p.m.

4. At moderate excitations, such as 4,000 ampere-turns per coil, the H.P. absorbed increases, except at first,* nearly with the speed up to 1,000 r.p.m. (see Fig. 14). Above this speed, however, there is a noticeable falling off. At low excitations, such as 1,500 ampere-turns per coil, the falling off occurs at about 600 r.p.m. This failure to reach proportionality is due to increased distortion of field at high speeds and

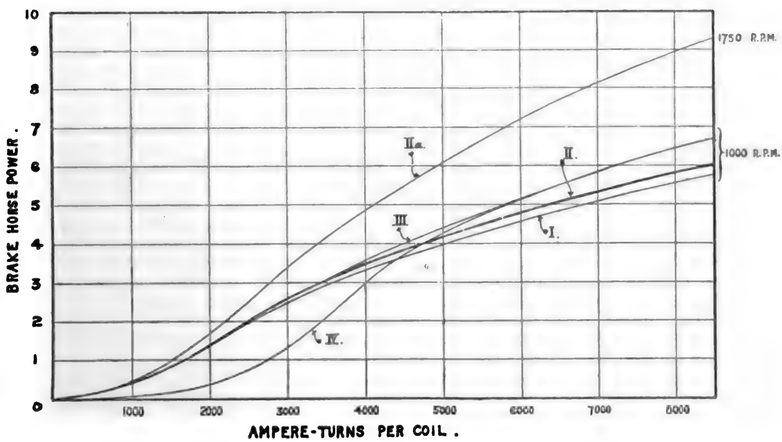


FIG. 4.

consequent reduction of resultant flux. Fig. 3A represents the flux (obtained ballistically) in one of the yoke-rings with the brake stationary, and also when running at 1,000 r.p.m., the excitation being constant at 3,500 ampere-turns per pole. The flux which usefully cuts the copper may be taken as that which actually arrives at the yoke-ring. The dotted curves, which are determined from the flux curves, represent the approximate induction density in the air-gap in each case. It will be seen that, on the average, the flux is shifted forward in the direction of rotation. This is represented in Fig. 3B.

5. The brake was originally made with a plain yoke-ring without pole-pieces. Its performance under these conditions is shown in Fig. 4, Curve I., abscissæ representing ampere-turns per pole, and ordinates the H.P. absorbed. The addition of pole-pieces 1 cm. deep,

* When the speed is small, the H.P. increases with the *square* of the speed. This is shown experimentally in the Appendix.

and having a radial length slightly less than the diameter of the magnet-core, somewhat increased the efficiency of the brake, as indicated by Curve II. The best position for the pole-piece was found to be 5 mm. forward of the magnet coil, but the effect was not sufficient to warrant their being permanently placed in this position.

6. An attempt to prevent the flux from being dragged off the pole-pieces, and so prevent excessive lengthening of lines and consequent reduction of field strength was made by winding the yoke-rings with additional magnetising coils situated between the pole-pieces. There were 16 coils or two coils per magnet each consisting of 25 turns of No. 18 D.C.C. copper wire.

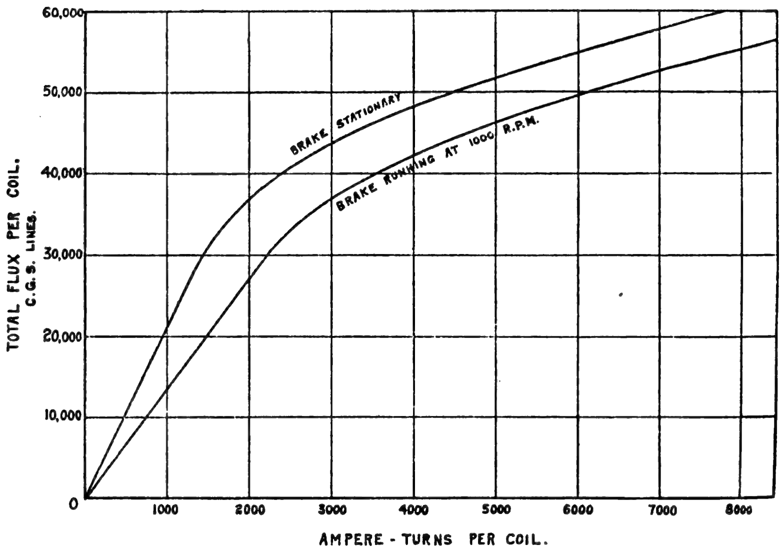


FIG.

The effect was very noticeable, as will be seen on reference to Fig. 4, Curve III., which shows the effect of a constant current in the main coils giving 3,500 ampere-turns combined with increased excitation applied by means of these supplementary coils, up to a total of 6,000 ampere-turns. Curve IV. shows the result of a constant excitation of 2,000 ampere-turns maintained by the yoke-ring coils, supplemented by currents in the main coils.

The result of these two curves is to show that, up to an excitation of, say, 5,000 ampere-turns, the maximum effect will be obtained by using the main coils only. Above this figure, however, the strength of the eddy currents in the discs tends to cause excessive distortion of the field, and a great advantage will result by transferring a large portion of the energy supplied to the brake to the yoke-ring coils. The advantage, however, probably does not warrant the extra complication.

7. It was found that the braking effect for a given excitation is not perceptibly dependent upon the temperature of the copper discs when working near the point of maximum torque. This shows that any decrease in the eddy currents due to increased resistance of path is counteracted by the consequently reduced distortion.

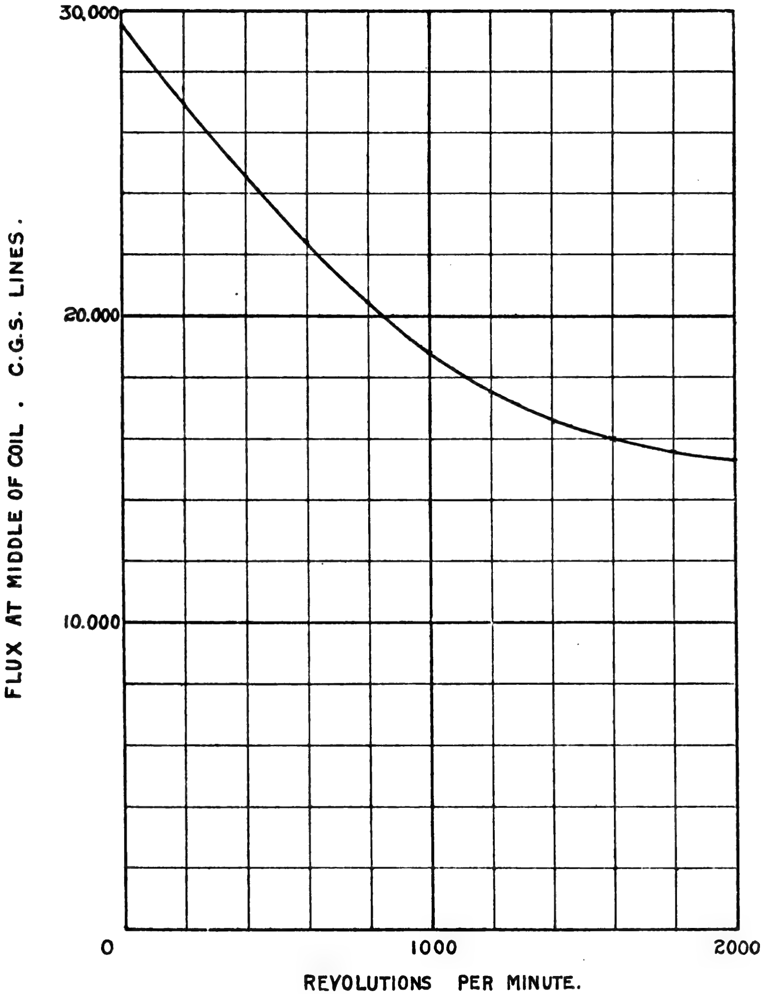


FIG. 6.

8. Experiments carried out with different lengths of air-gap emphasised the necessity of keeping this as small as possible. When absorbing 5 H.P. at 1,000 r.p.m., a reduction in the air-gap from 10 to 8 mm. reduced the current required by 15 per cent., thus resulting in a saving of power of rather more than 30 per cent.

9. Fig. 5 shows the variation of flux with excitation both with brake stationary, and when running at 1,000 r.p.m. The thickness of the copper disc is 4 mm., and the length of air-gap between pole-tips approximately 9 mm. In each case the flux was measured at the centre of the magnetising coil.

10. Fig. 6 shows the variation of flux with speed, the excitation being constant at 1,400 ampere-turns per coil. The measurements were taken at the centre of the coil.

Working of the Brake.

One of the characteristics of the brake is the steady manner in which the lever floats after the magnetising current has been adjusted. This is due to the fact that the centre of gravity of the sliding weights is slightly below the centre line. This feature is obtained without any material reduction in the sensitiveness.

Another noticeable feature when using the brake is the absence of trouble due to end-play of motor. This is extremely serious in the case of brakes in which the copper disc is mounted on the motor-spindle while the magnet system rests on a separate frame.

It is found that by the use of properly suspended flexible leads, the magnet coils can be supplied with current without the use of mercury cups.

The limit to the absorption capacity of the brake is determined by the heating of the magnetising coils. The fan action referred to on p. 447 is found to be an entirely satisfactory way of getting rid of the heat generated in the discs. Long-continued tests give rise to no difficulty at all on this account.

The brake was originally designed to absorb 5 H.P. when running at 1,000 r.p.m., and it has been found to work most efficiently at speeds of this order. At speeds above, say, 1,500 r.p.m. the falling off of braking effect due to field distortion becomes noticeable, and at speeds lower than 500 the magnetising current required to brake, say, 5 H.P. becomes too great for the capacity of the coils. Fig. 4, Curve II., shows the absorption capacity of the brake for given excitations at 1,000 r.p.m., and Curve II.A under same conditions for 1,750 r.p.m.

The brake is found very convenient for testing motors as regards temperature rise and overload capacity. When temperatures have settled down, and the magnetising current is finally adjusted, the load remains perfectly constant.

Motors may be tested for starting torque by locking the revolving discs to the fixed portion of the brake.

Figure of Merit.—In any type of eddy current brake it is important that the power absorbed in the magnetising coils be kept down as low as possible.

The ratio $\dfrac{\text{Absorption power of brake}}{\text{Power absorbed in magnetising coils}}$ may conveniently be termed the "Figure of Merit" of the brake. This figure should be as high as possible over the whole range of the brake, but more

especially at or near its full rated capacity. It is at this point it will be most frequently used, especially in connection with time tests. The figure of merit will, of course, rise with the speed.

Theory of the Eddy Current Brake.

(a) *Introduction.*—The theory of the eddy current brake is in many respects the same as that of the induction motor, with the additional simplification that inductance is absent from the rotor. The presence of poles, however, renders the ordinary induction-motor theory unsatisfactory. The theory here given is in many ways a very direct one. It takes account of the increase of reluctance of the air-gap due to the oblique path of the flux through the gap. This is not commonly done in dealing with the induction motor. It is not necessary when the slip is small, but becomes an important factor when dealing with starting torque.

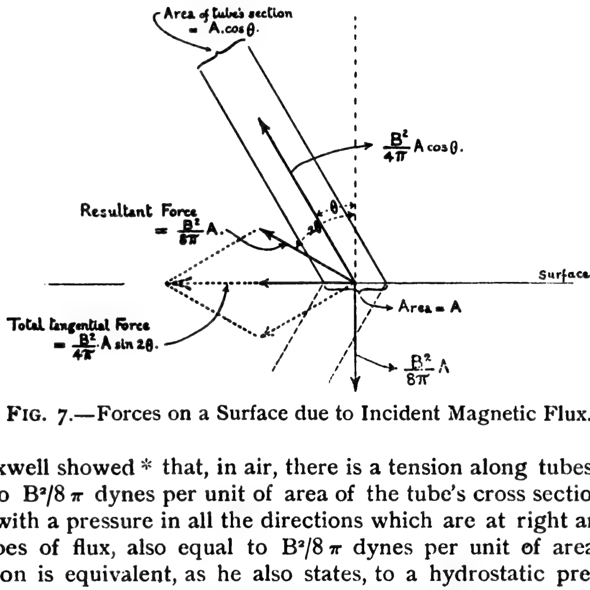


FIG. 7.—Forces on a Surface due to Incident Magnetic Flux.

Maxwell showed * that, in air, there is a tension along tubes of flux equal to $B^2/8\pi$ dynes per unit of area of the tube's cross section, combined with a pressure in all the directions which are at right angles to the tubes of flux, also equal to $B^2/8\pi$ dynes per unit of area. This condition is equivalent, as he also states, to a hydrostatic pressure of $B^2/8\pi$ dynes per sq. cm. combined with a longitudinal tension of $B^2/4\pi$ dynes per unit area of the tube's cross section.

Thus, if a tube of magnetic flux reaches a surface of area, A, at any angle θ, to the normal, so that its section is A . cos θ, then the two forces acting on that surface are as shown in Fig. 7; namely, a tension along the direction of flux of $\frac{B^2}{4\pi}$. A . cos θ, and a simple pressure upon the surface of $\frac{B^2}{8\pi}$ A. The resultant force on the area A

* *Treatise on Electricity and Magnetism*, vol. ii., pp. 280 and 281 (3rd Ed.).

is therefore $B^2A/8\pi$, and its direction is at an angle, 2θ, to the normal. So that the tangential force is $\frac{B^2}{8\pi} A \cdot \sin 2\theta$.

In the case of a brake disc, where the flux is bent so that it leaves at a similar angle on the opposite surface, the force is $\frac{B^2}{4\pi} A \cdot \sin 2\theta$; and, since $B \cos \theta$ is the flux density B_o as the flux crosses the surface normally, the force exerted by the magnetic field on the brake-disc area, A, is $\frac{B_o^2}{2\pi} \cdot A \cdot \tan \theta$.*

The flux produced in the air-gap by each magnetised-pole, can, if the latter are suitably shaped, be regarded as approximately sine-functional both when the brake-disc is at rest and when it is in motion. In the latter case, however, it is dragged forward in the direction of rotation on account of the magnetic action of the currents induced by the motion. The width of this equivalent sine-functional flux-band may be less than the pole-pitch if the poles are not sufficiently wide, as in the brake described.

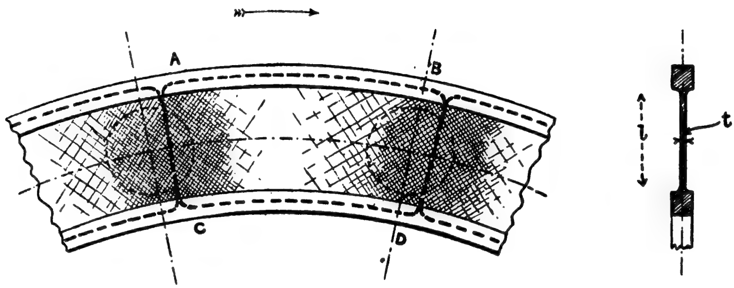


FIG. 8.

These induced currents give rise to a magneto-motive force tending to set up a flux lagging behind them in position by exactly half the pole-pitch. This magneto-motive force, however, operates upon a magnetic circuit of irregular and much greater reluctance than that of the original flux-path; and the greater it can be made, the less is the reaction caused by a given flow of eddy currents.

The eddy currents are at any point coincident in position with, and proportional in magnitude to the actual or resultant flux which crosses the disc at that point.

The eddy current paths remain fixed in space, so that the flux associated with them has not to be altered, and the energy corresponding to this flux is provided once for all. Only changes in this energy could

* The normal force can be similarly derived. Its value for an iron-cored armature, namely $\frac{B_o^2}{8\pi} A \cdot (1 - \tan^2 \theta)$, where $\tan \theta$ is evaluated as on p. 464, is an important expression which should be used when dealing with bending stresses on the shafts of running armatures when placed unsymmetrically with respect to the poles.

give rise to inductive effects (see Appendix). The current flow will, however, be slightly hindered as it enters the thick rims on account of skin effect.

The following notation is employed * :—

B_m =	maximum value of original or main flux ...	2,200 lines per cm².
B_r =	maximum value of resultant flux measured perpendicular to disc in the disc itself ...	1,370 " "
p =	width of equivalent sine-functional flux in cms. measured along pole-centre line ...	3·8 cms.
β =	ratio of this width to the pole-pitch ($p \div \beta$ = pole-pitch)	0·31.
b =	shift of resultant flux-wave from position of main flux...	0·55 cm.
a =	radius of swing of flux lines (see p. 460) in cms.	0·7 cm.
t =	thickness of disc in cm.	0·4 cm.
$2g$ =	gap between pole-faces in cms.	0·9 cm.
ρ =	specific resistance of material of disc in c.g.s. units per cm.-cube (hot)	2,450.
l =	radial length of average eddy-current path (see Fig. 8)	2·25 cms.
a =	resistance factor, (see p. 463)	2.
v =	speed of disc at effective pole-centre line in cm. per sec.	1,520 cms. per sec.
R =	speed of motor in r.p.m.	1,000 r.p.m.
D =	diameter of disc at pole-centres in cm. ...	29 cms.
x =	distance measured along disc at pole-centre line in cms.	

It will readily be seen that if the bands of flux be developed along the line of pole-centres on the disc, as in Figs. 9A and 9B, then the original or main flux can be denoted by

$$B_m \cos \frac{\pi}{p} x, \quad \text{between} \quad x = -\frac{p}{2} \quad \text{and} \quad x = +\frac{p}{2},$$

and the resultant flux by

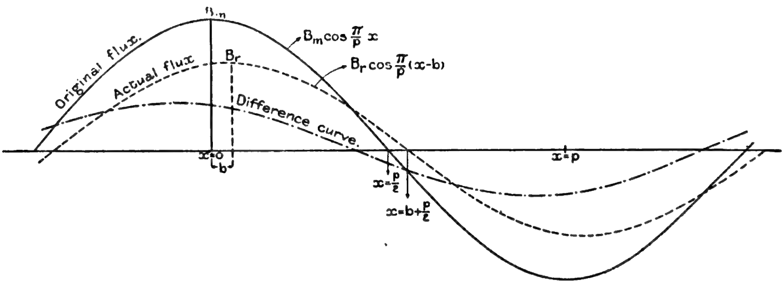
$$B_r \cos \frac{\pi}{p} (x - b), \quad \text{between} \quad x = b - \frac{p}{2} \quad \text{and} \quad x = b + \frac{p}{2}.$$

(These limits need not be specified where the flux-band occupies the whole pole-pitch, *i.e.*, where $\beta = 1$.)

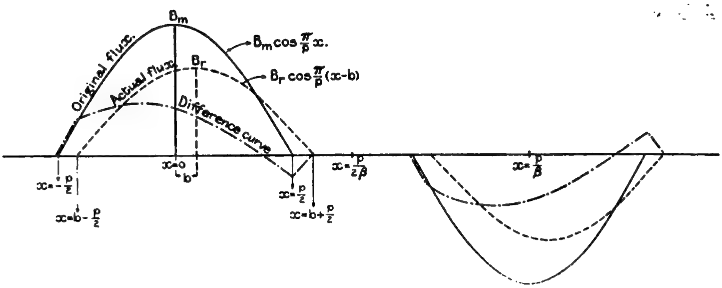
(b) *Flux-displacement.*—The flux across the gap when the disc is at rest is depicted in Fig. 10A; and when the disc is in motion, the flux is dragged forward in the direction of rotation as indicated in Fig. 10B, and is weakened in intensity owing to the increased length of the path in air. Thus a particular tube of flux meets with successive displacements with increasing disc-speeds in the manner shown in Fig. 11. The shift of the tube along the pole-face is restricted in amount by the

* The values given on the right are approximately correct for the brake described in the paper when running at 1,000 r.p.m., and excited so that it absorbs 3·1 B.H.P.

proximity of the forward edge of the pole. Thus, though the tube moves inside the pole-face nearly parallel to itself, the displacement of its path in the gap may be represented by rotations round fixed points, o, o′, inside the pole-face, whose position is dependent upon the formation of the pole. The distance of these points within the pole-face is very small (1 or 2 mm.), since it merely represents the excess reluctance of the whole magnetic path over that of the air-gap alone. In other words, the equivalent air-gap is greater than the actual.



(A) Width of flux wave equal to pole-pitch.



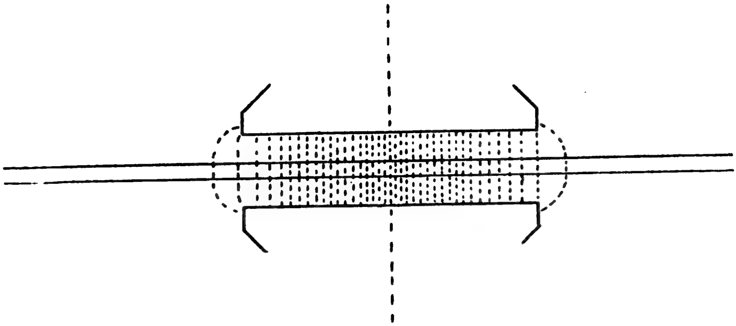
(B) Flux wave narrower than pole-pitch.

FIG. 9.—Approximate Flux Distribution—Standing and Running.

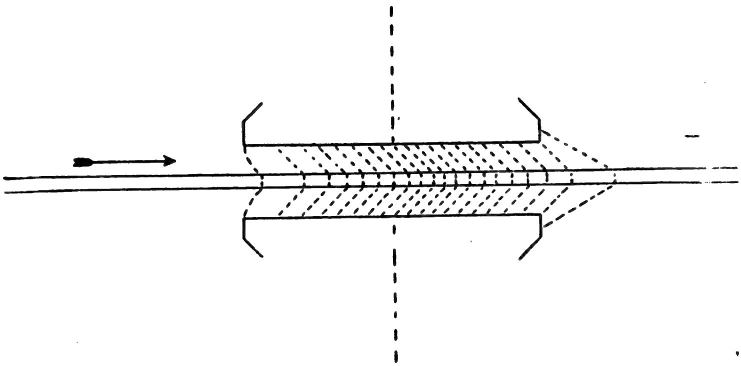
Assume that one such point, o, is *a* cms. from the central plane of the disc, and that this centre of rotation is situate at a similar distance for every tube of flux. The displacement of the tube as it crosses the disc is *b* cms.

Assume, further, that the reluctance of the whole magnetic path is dependent solely upon the length of its passage through the equivalent air-gap and the effective narrowing of the pole-surface due to forced obliquity of the flux.

The density of the oblique flux is therefore $B_m \,.\, \cos \frac{\pi}{p}(x - b) \,.\, \cos \theta$, which is further reduced to $B_m \,.\, \cos \frac{\pi}{p}(x - b) \,.\, \cos^2 \theta$ as it crosses the disc, owing to the increase in the tube's cross section. This expression then takes the place of that for the resultant flux given on p. 459.



(A) Flux in gap when disc is at rest.



(B) Flux in gap when disc is in motion.

FIG. 10.

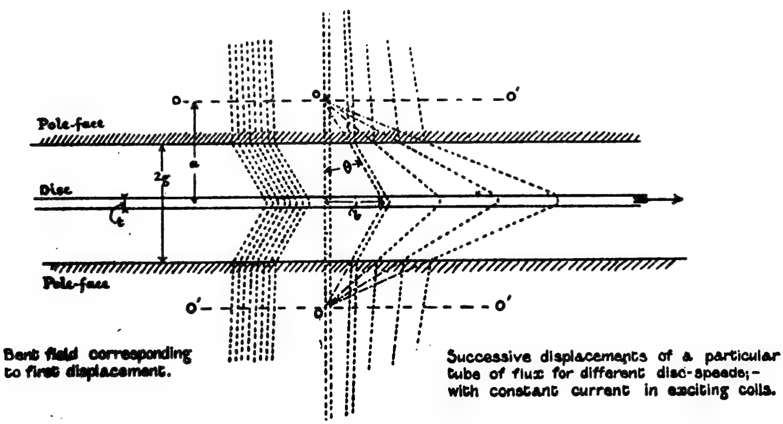


FIG. 11.

Consider an element of the surface of the disc of radial length l, and width dx. The retarding force on this element is (see p. 458)—

$$\frac{1}{2\pi} \cdot B_m^2 \cos^2 \frac{\pi}{p} (x - b) \cdot \cos^4 \theta \cdot l\, dx \cdot \tan \theta,$$

where $\theta = \tan^{-1} \dfrac{b}{a}$.

The force per pole is obtained by integrating this expression between the limits $x = b - \dfrac{p}{2}$ and $x = b + \dfrac{p}{2}$; and, if the flux falls on the disc with a uniform slope as indicated in Fig. 10B, then the retarding force is $\dfrac{B_m^2}{4\pi} \cdot p\, l \cdot \sin \theta \cos^3 \theta$ dynes per pole.

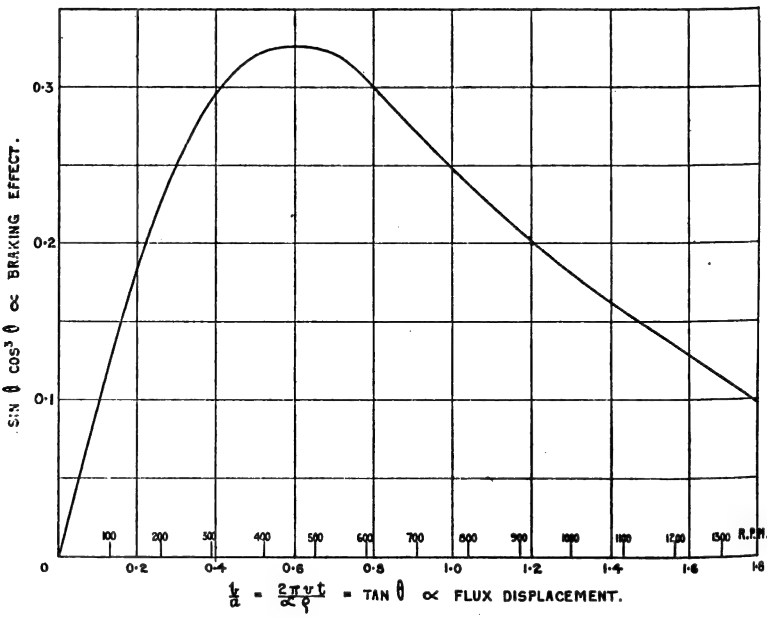


FIG. 12.—Variation of Torque with Flux Displacement.

To obtain the total retarding force on the whole disc, this expression must be multiplied by the number of poles, n; and, since $n \cdot \dfrac{p}{\beta}$ is the circumference, π D, of the pole-centre line of the disc, the total retarding force on the disc is

$$\frac{1}{4} \cdot B_m^2\, D\, l\, \beta \cdot \sin\theta \cdot \cos^3\theta \quad \text{dynes}$$

exerted at radius $\dfrac{D}{2}$. The disc thus absorbs

$$\frac{1}{10^7} \cdot \frac{\pi}{4} \cdot B_m^2\, D^2 \cdot \frac{R}{60} \cdot l\, \beta \cdot \sin\theta \cdot \cos^3\theta \quad \text{watts,}$$

or

$$1{\cdot}76 \times 10^{-12} \;.\; B_m^2 \; D^2 R \;.\; l\beta \;.\; \sin\theta \;.\; \cos^3\theta \quad \text{B.H.P.}$$

This can also be written as

$$0{\cdot}44 \times 10^{-12} \frac{N_t^2 R}{l.\beta.} \sin\theta \cos^3\theta \quad \text{B.H.P.}$$

where N_t = total passage of flux across the disc when at rest $\left(= \frac{2}{\pi} B_m\, p\, l\, n\right)$.

(c) *Slope of Flux for Maximum Torque at a given Speed.*—The expression $\sin\theta \cos^3\theta$ varies in the manner indicated in Fig. 12. It is easily shown that its maximum value, 0·325, occurs for $\theta = 30°$. The curve is plotted to a base of $\tan\theta$ since $b = a \tan\theta$.

Thus the best inclination of this flux in the gap is when $\frac{b}{a} = \frac{1}{\sqrt{3}} =$ 0·577; and this occurs only when the disc has a thickness to be determined below.

The greatest amount of power that can be taken up in a given brake disc is therefore

$$5{\cdot}7 \times 10^{-13} B_m^2 \, D^2 R\, l\beta \;.\; \text{B.H.P.}$$

(d) *Best Thickness of Eddy-Current Disc.*—The bands of flux which cross the disc were found to have a density (B) at the point of crossing of

$$B = B_m \;.\; \cos^2\theta \;.\; \cos \frac{\pi}{p}(x - b).$$

Consider a radial element of the disc (see Fig. 8) of length, l, and average section, $t \,.\, dx$. The E.M.F. induced in it is $B \,.\, l \,.\, v$. But the resistance of the circuit in which this E.M.F. has to operate is greater than $\frac{l\rho}{t \,.\, dx}$ by one-half the resistance of the portions A B and C D. Let the increased resistance be $\frac{a \,.\, l\rho}{t \,.\, dx}$, where a should have a value of 1·2 to 1·5.

The actual path of the currents will be approximately radial only when the rims are thickened, as shown in Fig. 8.

Since inductive back E.M.F. does not arise in the eddy current path, the current induced in the element is

$$dc = \frac{v\,t}{a\,\rho} B \;.\; dx,$$

and the current per cm.-width of disc is dc/dx.

This will cause at the surface of the disc a flux of $2\pi \,.\, dc/dx$ lines per sq. cm. parallel to the surface, and a similar flux oppositely directed on the other surface of the disc. The bend in the magnetic lines as they pass through the disc is effected solely by these two fields.

In order that a flux of value B may be bent through an angle θ by

a flux of $2\pi\,dc/dx$ at right angles to it, it is necessary that the former be related to the latter in the ratio $1 : \tan\theta$ (see Fig. 13), or as a to b. Hence, inserting the value of dc/dx, the flux-displacement is given by

$$b = a \cdot \frac{2\pi v t}{a \rho},$$

also

$$t = \frac{a\rho}{2\pi v} \cdot \frac{b}{a} \text{ cm.} = \text{thickness of disc.}$$

Inserting the most advantageous value of b/a already determined, it is seen that the eddy current brake disc should have a thickness between the pole-pieces of

$$t = \frac{a\rho}{2\pi\sqrt{3}\,v} = 0{\cdot}092\, a \frac{\rho}{v} \text{ cms.}$$

Any greater thickness will result in *decrease* of torque.

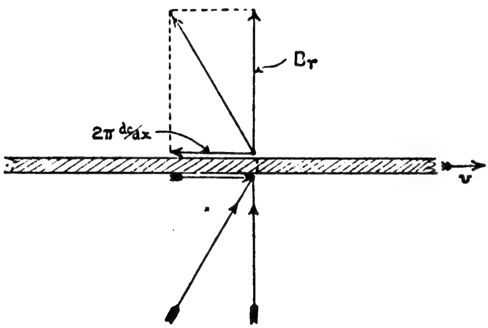


FIG. 13.

(c) *General Expression for B.H.P. Absorbed by Eddy Disc.*—The power absorbed by an eddy brake disc with radial current-flow is

$$1{\cdot}76 \times 10^{-12}\, B^2_m\, D^2\, R\, l\, \beta \sin\theta \cos^3\theta \quad \text{B.H.P.},$$

where

$$\theta = \tan^{-1} \frac{2\pi v t}{a\rho}.$$

The values of $\sin\theta\cos^3\theta$ are given in the curve (Fig. 12).

APPLICATION OF THEORY TO DESIGN OF EDDY BRAKES.

This theory leads to the following points of design :—

(1) The rims of the brake disc should be thick compared with the thickness between opposing pole-faces, so that the currents may flow approximately radially (Fig. 8).

(2) When this condition is attained the brake disc's thickness in millimetres should be about equal to the specific resistance of its material in c.g.s. units when heated—say about 2,500 for copper and

4,000 for aluminium—divided by the average linear velocity of the disc. For the brake described in the paper, when running at 1,000 r.p.m. or a mean linear velocity of 1,600 cms. per second, the best disc-thickness is about 1·7 mm. if the disc rims were thickened, and probably about 3 mm. with a plain disc.

(3) The magnetic circuits must be well designed in order that the point round which the lines of flux swing shall be but little within the pole-face. It is also proposed to meet this condition by a series of radial cuts or narrow slots in the pole-face. The observations on the brake described in the paper show that this point of swing is at present on the average about 2·5 within the pole surface (see Fig. 11), while the flux displacement with the 4 mm. disc. is about 0·6 cm. Under these conditions it will be seen that the eddy currents' M.M.F. is beginning to operate upon a better magnetic circuit, and not only to cause a reduction in the main flux, but also to give rise to a flux along the pole surfaces tending to increase the flux displacement.

(4) The radial lengths of the pole-faces should be as great as is convenient, the gap being made a shade less on the outside so that the flux may not suffer radial displacement. And, generally, the polar area should be increased (making β nearly equal to unity), and the gap reduced as far as practicable in order to economise in magnetising energy. A limit to this increase arises, however, if the magnet-cores are approaching saturation, on account of the diversion of the flux through the leakage-paths between the sides of the poles without crossing the disc at all (Fig. 3). Approximate investigation seems to show that the best value of β is about 0·6 when the pole-faces have a width rather less than one-half the pole-pitch. If an allowance of 25 per cent. be made for the reduction in flux arising through leakage combined with core-saturation, the following expression—

$$3 \times 10^{-13} B_m^2 D^2 R l \quad \text{B.H.P.},$$

would appear to represent roughly the *maximum* B.H.P. that can be absorbed in a given brake-disc running at the speed which is most advantageous for the thickness of brake-disc employed.

Putting $l = {\cdot}15D$, which represents a pole-face as long radially as is convenient, the expression becomes

$$4{\cdot}5 \times 10^{-14} B_m^2 D^3 R,$$

or, at 1,000 r.p.m.,

$$4{\cdot}5 \times 10^{-11} B_m^2 D^3.$$

For a disc 15 ins. in diameter over all, this becomes approximately

$$1{\cdot}35 \left(\frac{B_m}{1{,}000}\right)^2,$$

or 6·5 B.H.P. per disc, with the flux-densities occurring in the brake described in the paper. This brake, with its two discs, should therefore be capable of absorbing 13 B.H.P. at 1,000 r.p.m. if the best design could be followed.

Conclusion.

The authors have compared the theory here given with the results actually obtained on the brake described in the paper, and have found throughout as substantial an agreement as can be looked for, considering that the theory applies properly only to a copper disc with thickened rim.

When it is remembered that this brake was designed before the theory as to correct proportions was worked out, and that by (*a*) reducing thickness of disc, (*b*) providing it with rims as in Fig. 8, (*c*) widening the pole-faces, and (*d*) slotting them, an increase of capacity amounting to over 100 per cent. should result, it will be seen that it may fairly be claimed for the eddy current brake that besides being quite the most convenient and compact for ordinary motor-testing, it will compare favourably, when correctly designed, with mechanical water-cooled brakes, in all respects except that of initial cost.

A brake embodying these improvements is being designed, and it is hoped that an early opportunity will be found of constructing it.

In conclusion, the authors wish to express their thanks to the Council of the University of Birmingham, through whose action they have been enabled to carry out this work.

APPENDIX.

Since writing the Paper, the authors have carried out a number of experiments upon the brake with the object of testing the theoretical curve of variation of torque with speed. These experiments were made in groups, the speed being varied while the exciting current was kept constant.

The results of four such tests, selected from among a large number, are shown in Fig. 14. The similarity of the torque-speed curves to the theoretical curve shown on p. 462, Fig. 12, is apparent.

Two of these groups of observations were made with plain discs as shown in Fig. 1; and the other two with discs having thick rims of the section shown in Fig. 8. The latter section enables the length of the air-gap to be considerably reduced, while at the same time affording a path of high conductivity when flowing in a circumferential direction.

The curves for the two sections are not quite comparable on account of the difference in air-gap. They show, however, that when the magnetic circuit of a brake of this type is amply designed so that it is worth while working with a small air-gap, the disc with thickened rims is preferable to one of plain section, and the weight to be revolved is much reduced for a given braking effect. The curves shown full which apply to the thick-rim section are more closely in agreement with the theory than the others. With the plain section there is more copper between the opposing poles, so that eddy currents more local than those indicated in Fig. 8 predominate. The reaction produced by these more local currents even at high speeds is small, and the torque-speed curve, therefore, does not droop so much.

It will be seen that the maximum torque occurs at a greater speed

when the excitation is great. Thus with the thick-rimmed disc, while the maximum torque occurs at 500 r.p.m. with an excitation of 1,400 ampere-turns per coil, it does not occur until a speed of 650 r.p.m. is reached, when the excitation is 5,200 ampere-turns. This effect is due to the higher temperature of the discs at increased loads. The theory states that the maximum torque occurs for one particular value (0·577) of the slope of the flux in the gap; and it is clear from the expression for tan θ on p. 464 that, if the discs heat on account of greater load absorbed, the speed at which the maximum torque will occur must be greater also.

The statement occurs on p. 458 that only changes in the magnetic

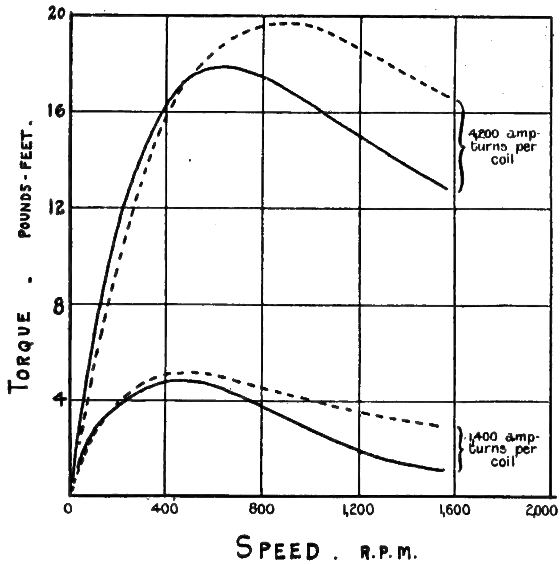


FIG. 14.

energy associated with the eddy currents can give rise to inductive delay in these circuits. By this is meant lag of eddy currents behind *resultant* flux. The inductance of eddy current paths can be regarded as made up of two parts:—One, corresponding to the flux associated with the portions AB, CD (Fig. 8), or with the end-connections in the rotor of an induction motor. This portion of the inductance is absent from the present problem because the eddy currents remain fixed in space. The other part corresponds to the flux associated with the portions of the eddy current path which are the seat of the induced E.M.F. The latter inductance properly includes only local flux round each rotor bar (in an induction motor), and is therefore also absent from the problem of the eddy current brake. The rest of the magnetic action of the induced currents is that which is spoken of in the paper as the eddy currents' flux, and may be regarded as consisting of a

tangential component, or "surface flux," on either side of the disc (dealt with on p. 463), and of a normal component, tending to send flux through the interpolar spaces, unless the shift of flux produced by reaction is great. The effect of this normal component is to strengthen the flux near the forward edge of each pole and to weaken it at the trailing pole-edge. That is, its nett effect is merely to increase the shift of the main flux-band. This increased shift is not dealt with in the theory given in the paper, since it is relatively small, owing to the polar formation.

It should be noticed that the slope of the flux as it reaches the disc is merely dependent upon the speed of the disc and its thickness. This appears at once from the value of tan θ, namely $2 \pi v t / a \rho$. The slope is the same whether the magnetic flux is strong or weak. The assumption in the paper of constant slope of flux over the whole pole-face is, therefore, justified with rectangular or radially-shaped pole-faces. If round pole-faces are used, the assumption of constant slope of flux will only be approximate. In the induction motor, the chief cause of unequal slope of magnetic flux in the air-gap is the existence of distinct rotor-bars; t has not a uniform value.

While the theoretical method of pp. 457 and 463 is unusual, it will be found to give the same results as the more usual methods when applied to any familiar problem of force in electrical machinery.

The authors' attention has been called to the following papers which bear upon the theoretical portion of the present paper:—

"An Approximate Method of Finding the Forces Acting in Magnetic Circuits," by R. Threlfall, F.R.S., *Phil. Mag.*, vol. 38, p. 89, 1894.

"The Magnetic Force due to a Current in a Wire Parallel to the Axis of a Cylinder of Iron," *Electrician*, vol. 40, p. 453, 1898.

DISCUSSION.

Mr. Lea.

Mr. H. LEA: I agree that to test a motor by coupling it either directly or by belt to a generator of known efficiency is but an indirect method. Under certain conditions the belt loss may be comparatively large, and it may be subject to variation. Where an accurate test is desired this method is consequently not to be depended upon. I consider that a mechanical brake might be devised which could be attached to the motor spindle, and which would be equally satisfactory and less costly than the eddy current brake described. For instance, the mechanical brakes on motor cars, although quite small, are capable of absorbing a large amount of power. That the heat is not conducted to the bearing, and that the brake can be mounted on the motor spindle, are very valuable features of the brake described by the authors. I think that the method of testing motors with variable bearing pressure cannot be depended upon. The pressure on the bearing at the pulley end can be adjusted, but this will result in varying pressures on the other bearing, which will not be under control.

Dr. W. E. SUMPNER: I admire the form of brake which the authors have designed. I think that supporting the whole brake on the motor spindle is a very beautiful device. I consider that the brake combines the theoretical accuracy of the Prony brake with the simplicity and convenience which results from the use of a generator as a load. It absorbs the power of the motor in three ways—by the action of the eddy currents in the disc, by bearing-friction, and by air-friction. The effect of each of these is taken account of by the weighted lever. I notice that the friction effects amount to about 1 per cent. of the total torque. The authors have developed a new form of theory in connection with this brake, based on the law which has been stated by Maxwell, but which has been very seldom applied. I am struck by the similarity of the curve (Fig. 12), showing variation of torque with flux displacement, with that connecting the torque and slip of an induction motor. There is a very remarkable correspondence, though the method in the paper is quite different from that commonly employed in dealing with the induction motor. In the case of the induction motor, the field revolves with respect to the rotor, while with the brake the fields are fixed and the discs revolve. With the motor, the slip depends upon the difference between the rotor speed and the speed of synchronism, while with the brake the speed of revolution is practically slip. As in the case of the motor the torque depends upon the resistance of the rotor circuit, so in the brake there will be a certain resistance or thickness of disc which will give maximum torque. Dr. Sumpner.

Mr. E. MARPLES: I do not consider the Hopkinson method as altogether satisfactory. When the motor is fully loaded the generator is not, so that to take the mean efficiency does not give a correct result. I should like to have more information as to the exact mode of calculating the B.H.P. from the observed results. The eddy current brake is an ideal method of absorbing power for time tests to determine heating. Mr. Marples.

Mr. R. A. CHATTOCK: The brake described is simple, handy, and very suitable for small powers. If, however, it is made sufficiently large to absorb 30 or 40 H.P. I think it would become too cumbrous. It would be a costly method of testing on account of the energy which must be supplied during the test. With a large size of brake, I consider that the heating of the field coils would be much greater than in the case of a small size. Mr. Chattock.

Mr. R. ORSETTICH: I have used the Pasqualini and Rieter types of brakes. In the former I have had trouble in connection with the centring of the disc, and in the latter with the heating of the magnetising coils. I have experienced difficulty with the mechanical type of brake from excessive heating. The most important thing in connection with the type of brake described by the authors is the method of putting it on the motor shaft. This obviates any necessity for adjustment. The weak spot is the amount of energy consumed. I consider that the theory might be applied to the design of the brake discs used in meters. I would like to know whether it is usual to design these Mr. Orsettich.

Mr. Orsettich. discs theoretically or whether the best form of disc is determined by experiment.

Mr. Holden. Mr. S. H. HOLDEN: I have had considerable experience with the eddy current brakes used on meters. But with these one never reaches a speed at which the weakening of the field becomes noticeable, so that the retarding torque is always practically proportional to the speed. It seems incredible that the power absorbed should be proportional to the speed only and not to the square of the speed, but the authors have made this quite clear in the paper. I notice that in Fig. 3, the pole-pieces are shown as having bevelled edges. I have found plain poles, as in Fig. 10, much better. With reference to the authors' statement that the braking effect depends merely upon the total flux cutting the copper, I do not think that they would have got such a good braking effect had they used 2 instead of 8 poles. In connection with meter discs, I have experimented upon the best shape of pole piece. With circular, square, and rectangular poles of equal area and flux density, I found the circular shape produced an effect greater than that caused by the square pole in the ratio of 8 to 7, and that the rectangular shape is much inferior to either.

Mr. Brew. Mr. W. BREW: I am much interested in the way in which the authors have shown that the braking effect depends on the speed and resistance of the brake disc. The similarity of the brake described to the induction motor to which Dr. Sumpner has called attention has also much impressed me. I consider that the figure of merit is extremely important, and I would like to know the performance of the brake in this respect. I suggest that, in order to reduce the waste of power, it might be possible to mount a generator on the motor shaft, taking the weight in the manner described.

Mr. Bate. Mr. A. H. BATE: The authors' brake will be a valuable adjunct on all testing floors. With regard to the Soames brake, I consider the limit to be about 3 H.P. When using it for larger outputs, there is a tendency for the steelyard to bend. During the demonstration I have been impressed by the sweetness with which the authors' eddy current brake has worked. It seems to me that special apparatus in the form of rheostats, &c., will be required for the working of the brake. It may not always be convenient to provide a suitable voltage for the magnetising coils. Is it possible to arrange the connections so that the coils could be connected up in various ways to suit any voltage?

Mr. Field. Mr. M. B. FIELD (*communicated*): The authors' attempt to calculate the drag in a copper disc moving in a magnetic field is interesting. It should also prove helpful to others studying the braking effects in meters and similar apparatus. The method employed reminds me of an article by Mr. G. F. C. Searle, on the magnetic force due to a current in a wire parallel to the axis of a cylinder of iron, which was published in *The Electrician* of Jan. 28, 1898, p. 453. If we could determine the inclination and density of the magnetic lines at the boundary surface, Maxwell's rule of hydrostatic pressure, superimposed upon tension, enables us in a simple case to calculate the force exerted. The authors' assumption that all the lines of force emerge from the

surface of the disc at the same angle is only tenable when the path of the eddy currents is a straight radial line, such as is shown in Fig. 8. This would be the case were the edges of the disc infinitely conducting, and were the induction, normal to the disc, uniform at all points in the radial line. The current density at every point would then be proportional to the value of the normal induction, and the tangential magnetic force being proportional to the current density, the resultant of this and the normal component would make the same angle with the plate surface at all points. Such conditions render it unnecessary to assume sinusoidal or any other distribution of flux. But in the authors' case the normal flux density varies from point to point of a given line of eddy current flow, the electric potential is not, in general, constant, and it is no longer possible to assume that all the flux lines leave the surface parallel with each other. A particularly suggestive point is the critical thickness of the disc which gives maximum braking effect. If the discs were infinitely conducting, I suppose that the flux would be dragged forward by half the pole pitch, the disc currents would then occupy the most favourable position for demagnetising, and the resultant flux would be reduced to the vanishing point. Instead of varying the thickness of disc, the authors might have varied the specific resistance. It would be interesting to have some tests with cast-iron discs of the appropriate thickness to give maximum eddy current loss at some safe speed, and to study the effect of the superposed hysteresis drag. A second noticeable point is the similarity of the curve in Fig. 12 to the torque-slip curve of an induction motor. In connection with meter damping discs it is a mistake to suppose that circular pole-pieces give the best results, as the eddy currents do not circulate round the poles, but traverse them. If a narrow rectangular pole face is used, the braking effect is much greater when the disc is moved across the face, than when moved in the direction of the length of the face. Considering only that portion of the disc which is under the pole, the C^2R loss is approximately the same in either case. The observed difference in braking effect must therefore be due to the resistance of the eddy current paths not under the pole. In an extreme case where the pole is very long and narrow, we see that in the first case this resistance is many times greater than that of the portion lying under the pole, while in the second case, practically the whole resistance of the eddy current path is contained within that portion lying under the pole itself. If the eddy current paths are in any way restricted by boundaries or edges of the disc, these deductions must naturally be modified accordingly. Mr. Field.

Mr. A. SCHWARTZ (*communicated*): All who have used the eddy current brake for testing purposes will agree as to its general advantages, although with the forms of brake now on the market a good deal of trouble is necessary in setting up and connecting to the machine to be tested. The authors seem to have successfully overcome these troubles in their new form, and have given us a very useful appliance for the testing of small motors. They are to be congratulated on the ingenuity of these methods, and the workmanlike appearance of their brake. Mr. Schwartz.

Mr. Schwartz.

The cradle dynamometer method of testing, as an alternative to the eddy current brake, is worth considering, particularly for use with larger machines than those dealt with by the authors. In the Municipal School of Technology, Manchester, we use a cradle dynamometer for motor testing designed by Mr. A. E. Moore, and made in the school shops. It consists of an adjustable base plate radially suspended from two beams with hollow trunnions on ball bearings. A counterpoise weight is provided on the cradle for adjusting the centre of gravity of the oscillating system. The torque is preferably measured by a zero method, as this eliminates any error due to the centre of gravity of the cradle and motor not being coincident with the axis of oscillation. This is effected by the use of a spring balance or a weighted lever. With a belt drive, machines can be rapidly put in position and run on the ordinary commercial tests, with the advantage that the B.H.P. can be obtained at any time during the run. The cradle is also suited for the determination of the mechanical and electrical losses, starting torque and other detail tests. The old knife-edge form of cradle is only suited for small motors, but the employment of ball or roller bearings extends the use of the cradle dynamometer to fairly heavy machines. The machine under test may be driven either by direct coupling or by belt, or in the case of a motor it may drive any suitable size of machine as a load. No correction is necessary for slip of belt. I would like to know the largest size of eddy current brake which the authors consider practicable having regard to the cost, and also whether they can give any particulars as to cost and working of the very large eddy current brakes employed by Körting in conjunction with their gas engine flywheels.

Mr. Smith.

Mr. C. F. SMITH (*communicated*): In using eddy current brakes I have found the easy method in which the load is adjusted to any desired value to be a great advantage. Thus, in taking a complete efficiency curve of a motor, the sliding weight on the arm of the brake can be adjusted to an exact point on the scale, and the pull of the brake is then adjusted by means of a finely divided rheostat in the exciting circuit of the brake, until the motor exactly balances the load. The weighted lever is then again adjusted to the next convenient scale division for which a reading is required, and the adjustment of the load on the motor is again made gradually and with the greatest ease by means of the rheostat, without touching the moving arm. The same advantage of easy adjustment makes itself still more felt when it is desired to load the motor rapidly up to a certain definite point—say the normal full-load of the motor. A rapid calculation is made to determine the position of the sliding weight corresponding to this load. After placing the weight in the position thus determined, the rest of the adjustment is performed entirely by the field rheostat of the brake. When this method of load adjustment is contrasted with the repeated trials and changes of load which are so often necessary when weights and a spring balance are employed, the material advantages offered by eddy current brakes, from this consideration alone, become apparent.

Professor Robertson.

Professor D. ROBERTSON (*communicated*): I have lately used a mechanical brake of the James Thomson pulley type which I have found con-

Professor Robertson.

venient for the testing of small motors. This is a rope brake, in which the light end of the rope is attached to a frame carried on the pulley. The torque is balanced by a weighted cord passing round a portion of the frame in the form of an arc struck from the centre of the pulley. The motion of the frame round the pulley, which is limited by stops, adjusts the arc of contact to suit the coefficient of friction within considerable limits. The load for any given torque is thus automatically kept constant. I have made a brake of this type suitable for machines up to 10 B.H.P., and I have found it to work satisfactorily, there being practically no hunting.

Dr. Morris.

Dr. MORRIS (*in reply*): In reply to Mr. Lea, the compactness of mechanical brakes on motor cars is largely due to special circumstances, the speed admitting of efficient cooling, and the brake under no circumstances being used for long periods. Pressure on motor bearing due to external causes actually occurs to a known and varying extent in most cases, and it is an advantage of the eddy current brake described in the paper, that the motor can be tested with any desired pressure on the bearing, that is, under any practical condition of working.

With reference to Dr. Sumpner's remarks and those of Mr. Field, I consider that the similarity of the torque-speed curve for the brake, to the torque-slip curve of the induction motor is perhaps, to some extent, apparent rather than real. An essential feature of the former is the reduction in flux due to its obliquity and the consequent increased length of passage through the air gap; while in the induction motor, the flux is substantially constant on account of the constancy of the applied voltage. It is lag of induced currents, rather than reduction of flux, which causes much of the falling off in torque of an induction motor when the slip is great.

In reply to Mr. Chattock, the advantages of the Hopkinson method for testing large sizes have been mentioned in the paper. Both Mr. Chattock and Mr. Orsettich have suggested that the brake is not suitable for large sizes. Mr. Lister no doubt agrees with me in the opinion that there is no limit from constructional reasons to the size of this type of brake; in fact, the larger it is made, the more economically it can be designed. The real limit is imposed by the need for saving the power spent in driving the motor when this exceeds say 15–30 B.H.P., *i.e.*, when the Hopkinson method becomes fairly applicable.

In connection with Professor Schwartz's remarks, I do not regard it as at all certain that the cradle method is more suitable for larger sizes than the type of eddy current brake described in the paper.

As Mr. Holden has said, it is plain that where the torque is independent of the speed, the power is merely proportional to the speed; while when the torque is proportional to the speed, as at first (Fig. 12), the power is dependent upon the square of the speed. Mr. Holden's remarks, and especially those of Mr. Field, upon the influence of the shape of the pole-pieces are of great interest in connection with the design of the brake. In reply to Mr. Brew, it appears clearly from the expression on p. 464 that there is only one best thickness for the brake disc for a given speed.

Dr. Morris. Mr. Bate has asked whether the coils can be excited from various voltages by connecting them in parallel or series as required. This arrangement has been used by the authors, but it would probably be best to fix the voltage once for all. I am much gratified by the way in which this new form of electric brake has been received, and by the appreciation expressed for the authors' efforts to give a working theory for the design of such brakes.

Mr. Lister. Mr. LISTER (*in reply*) : I have little to add to what has already been said by Dr. Morris. Mr. Brew has asked for information regarding the figure of merit. In the brake described, when running at 1,000 r.p.m., this varies from 13 at 2-H.P. to 5 at 5-H.P. We believe that by the aid of the theory and the experimental results obtained, the figure of merit can be considerably increased in future designs. In any case the power absorbed by the brake will always be small compared with that supplied to the motor, and is unimportant, since the latter is often entirely wasted when carrying out motor tests.

GLASGOW LOCAL SECTION.

ALTERNATING-CURRENT MOTORS IN INDUSTRIAL SERVICE.

By P. D. Ionides.

(*Paper read May* 9, 1905.)

There are three factors in electrical engineering at the present day which tend to make the use of alternating-current motors more general, apart from the universal recognition and appreciation which the alternating-current motor is obtaining for itself. These are:

(1) The presence in almost every industrial centre of electrical power distribution companies supplying power over distances, which absolutely necessitates the use of alternating currents.

(2) The increasing popularity of the steam turbo-generator in private industrial plants.

(3) The new regulations issued by the Home Office for the use of electricity in mines.

In the first case the supply is necessarily alternating current, and consequently the supply companies can sell their alternating current at a cheaper rate than they can sell direct-current, so that it is to the advantage of the consumer to use alternating-current motors.

In the second case, while it is recognised that direct-current generators for coupling to steam turbines have been built and operated satisfactorily, nevertheless no engineer having the choice of laying down a direct-current or alternating-current turbo-generator would choose the former if he could accomplish his purpose with the latter.

In the third case, the new mining rules are such as to render compliance therewith much more readily accomplished by the use of alternating-current motors.

As a result, it follows that a good deal of attention is now directed towards the alternating-current motor with a view to accomplishing as good results in all classes of power-driving as have until recently been considered practicable only by the use of direct-current motors.

In Scotland the adoption of alternating currents in private industrial concerns has not been so rapid, or general, as in England, and in the United Kingdom the proportion of alternating-current plants to direct-current plants is very small as compared with the practice on the Continent and in the United States of America.

The reasons are not far to seek. We have no water-power avail-

able for the generation of electricity within reasonable distance of the markets for power; consequently there are few high-tension alternating transmission plants, with the exception of those installed for large tramway or railway undertakings. Moreover, the question of obtaining way-leaves for overhead transmission lines has been, and still is, to a great extent a matter of considerable difficulty.

As a consequence the absolute necessity of using alternating currents has not made itself felt. On the Continent, however, and in the United States of America, alternating-current high-tension transmission plants are very general. It is not surprising, therefore, that the alternating-current motor should have been more generally adopted in these countries.

The conditions here are now becoming very similar to those abroad, inasmuch as the large power distribution companies are increasing in number and scope, and also many large municipalities are adopting alternating currents for transmitting power from central stations to sub-stations, where the current is converted for lighting purposes.

In the author's opinion such municipalities as Glasgow, Manchester, Liverpool, etc., will shortly offer alternating current for power purposes at a lower rate than direct current, for the reason that the converting apparatus for a large alternating-current motor load is less expensive.

With these changes taking place it seems advisable to consider the application of the alternating-current motor to all sorts of industries, and with particular reference to such cases where it has been the general opinion that only direct-current motors could be used.

The great argument in favour of the alternating-current motor, particularly of the squirrel-cage type, is its simplicity and the absence of wearing parts. The almost universal argument used against the alternating-current motor, as compared with the direct-current, shunt-wound machine, is that it has not the advantage of shunt regulation for variable-speed work. It is true the speed of the induction motor cannot be varied in this way, but there are other ways in which different speeds can be obtained with equally high efficiency, and the author is inclined to think that the importance of being able to vary the standard shunt-wound motor 10 per cent. or 15 per cent. is frequently very much overestimated.

Before proceeding to describe some applications of the alternating-current motor, it seems well to mention the best known types, which are—

(1) *The Squirrel-cage Motor.*—The squirrel-cage polyphase motor, which can be wound for two or three phases, consists primarily of two parts, the stationary part carrying the windings which receive current from the supply circuit, and the rotating part which has no connection with the supply circuit. The stationary part is wound with coils similar to those used on the ordinary direct-current armature, while the rotating part carries the squirrel-cage winding, which gives its name to this type of motor. This winding consists of copper bars laid in the slots of the core, and connected at each end to heavy copper rings, the whole construction very closely resembling a squirrel-cage. The coils of the

primary or stationary part, although resembling the coils of a direct-current armature, are connected in groups overlapping each other, so as to form a certain number of poles. The polyphase currents connected to these windings set up a revolving magnetic field. The speed at which this magnetic field revolves is dependent on the number of poles and the frequency of the supply, *e.g.*, at 3,000 alts. per minute, or 25 periods per second in a motor wound for four poles the magnetic field will revolve at 750 r.p.m. To determine this figure, divide the number of alternations per minute by the number of poles with which the motor is wound.

At 3,000 alts. per minute and six poles the speed would be 500 r.p.m.

This revolving magnetic field induces currents in the secondary, or rotating part of the motor, and at no load the rotating part will revolve at almost the same speed as the magnetic field.

As the load is applied the speed of the rotating part lags behind the speed of the revolving field, thereby increasing the induced currents.

The amount by which the rotating part lags behind synchronism is dependent on the load, and generally termed "slip." At full load the "slip" of a motor designed for constant-speed work will be less than 5 per cent. It will be understood, therefore, that any change in the resistance of the secondary circuit will affect the "slip" of the motor and its starting torque.

The constant-speed type of motor can be built so that it will carry 200 per cent. overload with a comparatively small drop in speed, or by changing the proportions of the windings in the secondary the motor can be made to give its maximum torque at zero speed, or, in other words, at starting.

(2) *The Slip-ring Motor.*—This differs from the squirrel-cage motor only in the secondary, which is coil-wound, the windings being connected to three slip-rings for starting with resistance in the secondary circuit. Once the motor is started, and the secondary short-circuited, its characteristics are similar to those of the squirrel-cage type.

For starting up against very heavy loads, where gradual acceleration is required, this motor is preferable to the squirrel-cage type; moreover, starting against a given load, the starting current is not so heavy, and more closely resembles the results which can be obtained with the ordinary direct-current motor starter and shunt- or compound-wound motors.

(3) *The Single-phase Series Motor.*—This differs materially from the other types, inasmuch as it is not what is generally known as an "induction motor." This type more nearly resembles the direct-current series motor, and possesses both commutator and brushes. In fact, it will operate quite satisfactorily on a direct-current supply. This motor is nothing more than a direct-current series motor constructed to operate satisfactorily with rapid reversals of polarity.

It is well known that if the current in a direct-current series motor is reversed the direction of rotation of the motor will be unchanged, provided the connections between the series field and armature remain unaltered. Assuming, then, that the direction of current is

changed once every minute, the operation of the direct-current series motor will be satisfactory. The alternating-current single-phase motor is a step further. The direction of current is changed according to the number of periods per second, and it is found that quite satisfactory operation can be obtained with 25 periods per second, which is the standard frequency for many power installations. The whole motor is laminated to respond to these changes without undue loss, and the only difficulty which has arisen was in connection with the commutation. This difficulty has been entirely overcome by the use of compensating windings in the armature.

The Squirrel-cage Motor.—To deal with the squirrel-cage motor first. This type is used for all constant-speed work, such as driving line shafting and machine tools, and a variety of other purposes with which every one is familiar. It possesses the great advantage of extreme simplicity both in the motor itself and in the starting devices.

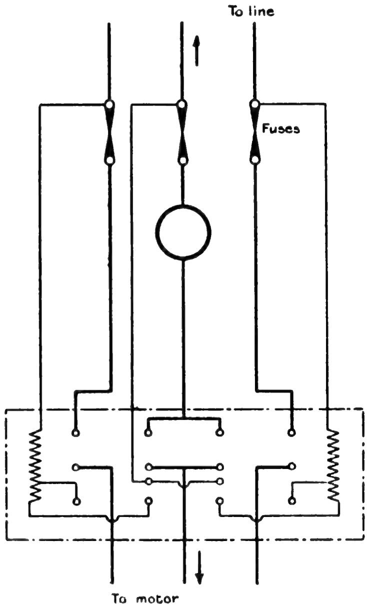


FIG. 1.

Fig. 1 shows a diagram of the usual form of auto-starter. The auto-starter consists of two auto-transformers mounted in an iron box with a double-throw four-pole switch. For starting, the switch is thrown to one side, connecting the line with the auto-starter, and furnishing current at a reduced pressure to the motor. This is to avoid shock to the supply system, and to prevent the motor starting with too sudden a jerk. After the motor has attained a fair speed the switch is thrown in the opposite direction, which connects the motor straight to the line.

The auto-starter is built in an iron box with a handle projecting through the cover, and both the auto-transformer and switch are immersed in transformer oil. With such a simple starting device, this particular type of motor and starter can be handled by the most unskilled operator.

Motors up to 10 H.P., obtaining their supply of current from a power-station of 200 H.P. or 300 H.P., can be started up direct without the use of an auto-transformer. This does not injure the motors in the least, but is not advisable where the generating plant is of small capacity as compared with the motors, inasmuch as it takes a very heavy rush of current at starting. It is also advisable to use a double-throw switch for the purpose of cutting out the fuses at starting, other-

wise the fuses, being of sufficient capacity to withstand the starting current, would be of no practical value as fuses, once the motor was started when the current is down to normal.

A third arrangement for starting the squirrel-cage motor is from a closed-coil two-phase generator, which is worthy of consideration when planning a new industrial plant.

Fig. 2 is a diagram showing the winding and E.M.F. between wires of a two-phase closed-coil generator, and Fig. 3 shows the manner in which a reduced E.M.F. can be obtained from the side circuits for starting the motor.

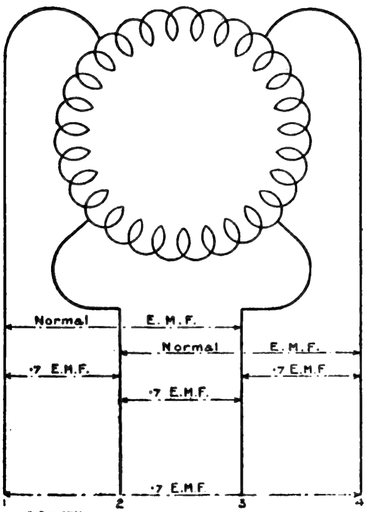


FIG. 2.

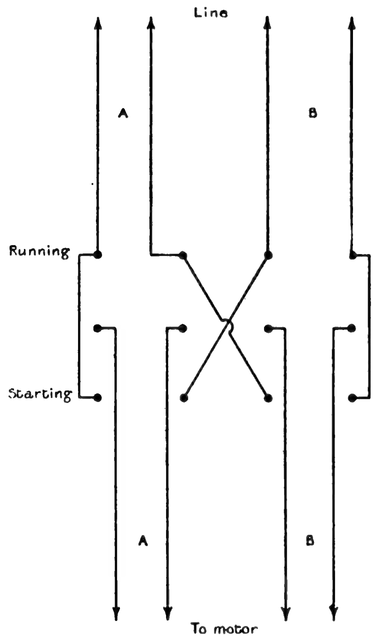


FIG. 3.

In regard to the starting torque, it is frequently stated that the squirrel-cage motor is incapable of starting up against full load. This is quite incorrect, for as much as three times the full load torque can be developed at starting, while in the smaller sizes two to two and a half times the full load torque can be developed; but, at the same time, the current to obtain such starting torques would be very heavy. To obtain a starting torque equivalent to full load torque it requires roughly two and a half times full load current in almost all sizes of motors, but as this requirement is only momentary, it is of little consequence.

The starter can be placed remote from the motor, and, in certain circumstances, this is a matter of great convenience.

For general constant-speed work the squirrel-cage motor possesses the advantage of greater simplicity, and has no disadvantages as compared with the direct-current motor. For driving spinning machinery it is particularly suitable by reason of the fact that within certain limits the speed is constant in relation to the speed of the generating plant, and independent of slight fluctuations in voltage. The importance of constant speed for this work cannot be overestimated. Again, in spinning mills and such industries it is of the utmost importance that all machinery should be started simultaneously, otherwise troubles are likely to ensue with the employees. The squirrel-cage motor lends itself to this requirement very readily, as it is possible to leave all the motors in an installation connected direct to the line, and to start them all simultaneously by separately exciting the generator and then running up the engine.

For mining work, such as the driving of pumps, fans, underground haulages, the squirrel-cage motor is particularly suitable, inasmuch as there are no parts other than the bearings requiring attention; again, the oil-immersed auto-starter, which can be made water and gas tight, is a form of starting switch which needs no skill or knowledge in handling. In many pits where there are explosive gases no other type of motor could be used with the same safety.

The high lift turbine pump is gaining considerable popularity amongst mining engineers, and for driving this type of pump direct the squirrel-cage motor is particularly suitable, inasmuch as motors of 100 H.P. and above are frequently required at a speed of 1,400 to 1,500 r.p.m. A direct-current motor of this power and speed would not be a satisfactory machine to build or operate, but for this work the squirrel-cage motor presents no difficulties, provided a supply is available at a suitable frequency.

A valuable feature of the squirrel-cage motor, not previously mentioned, lies in the fact that it can be actually stopped by overload for as long as half a minute without damage.

The Slip-ring Motor.—For the driving of large haulages which must be started slowly and gradually the slip-ring motor is preferable. Any starting torque required within reasonable limits can be obtained without producing undue strain on the generating plant; in fact, with the slip-ring motor the proportion of current to torque developed by the motor is almost similar to the same proportion for shunt-wound direct-current motors.

For continual starting and stopping the slip-ring motor possesses considerable advantages over direct-current motors for this class of work. It is general to use a tramway type controller in each case, and whereas with the direct-current motor the currents broken by the controller are always at line pressure, with the slip-ring motor the currents broken are those in the secondary circuits of the motor, and at a low pressure. This feature adds to the life of the contacts.

Again, for electric braking the slip-ring motor can be used to great advantage, by so proportioning the resistance in the secondary circuit with the first or second notches of the controller as to produce a

gradual braking effect when the controller is reversed. This has been applied with marked success to a 150-H.P. slip-ring motor driving an endless haulage. Fig. 4 shows this arrangement diagrammatically.

Variable-speed Work.—For this all three types are used.

The industries most generally requiring variable-speed motors having a wide range of speed are those connected with the making of paper, printing, dyeing and bleaching. In some cases the speed variation required is so wide and so gradual as to preclude the possibility of using "induction motors," and until the recent development of

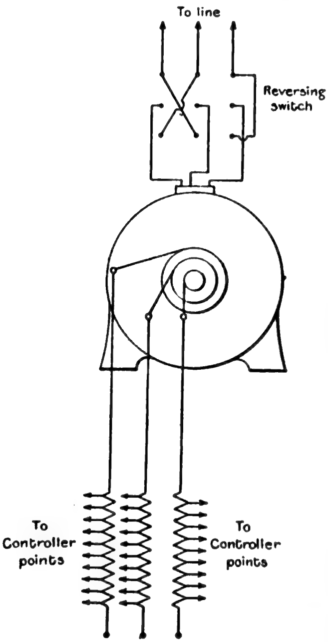


FIG. 4.

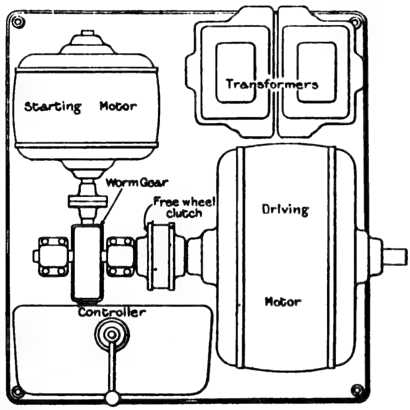


FIG. 5.

the single-phase series motor there was no alternating-current apparatus which could meet these requirements.

In the majority of cases, however, the requirements of speed variation can be met by the use of induction motors of either the squirrel-cage or slip-ring type.

For paper calenders the usual requirements are—

(1) The dead slow speed for threading in the paper;

(2) Minimum speed for calendering certain classes of paper;

(3) Top speed for calendering other classes of paper.

These requirements can be met in the following manner, as shown on Fig. 5:—

There is a small auxiliary motor driving the main motor through a

worm gear, and free wheel clutch, so as to give the required slow speed for threading in.

The main motor is wound and connected to a controller of the tramway type, so that the coils of the stator can be grouped to form eight poles, at which the medium speed would be obtained, or four poles, at which full speed would be obtained.

In this particular apparatus the supply is at 25 periods, and consequently the speeds of the motor are 360 and 720 r.p.m., making the usual allowance for slip.

The changing from dead slow to half-speed and from half-speed to full speed is obtained by means of tappings from a pair of auto-transformers and a number of notches on the controller, whereby a gradual increase in voltage is applied to the motor as the controller is moved from notch to notch. This ensures an even acceleration, and prevents any tearing of the paper.

It would have been equally feasible to have wound the motor with twelve and eight poles, so as to give three-quarter and full speed, or other combinations. The controller can be placed remote from the motors for the convenience of the operator, and all movements are controlled by one handle.

The whole apparatus is no more costly than direct-current apparatus to accomplish the same results would have been, and the operation is equally satisfactory.

A modified form of the arrangement just described for paper calenders can be used to great advantage on other classes of work; for example, in the driving of air compressors or hydraulic pumps.

In this arrangement the motor is wound for two speeds, *i.e.*, tappings are brought out from the windings so that the coils may be grouped to give full speed and half-speed, or full speed and three-quarter speed, as the case may be, and connected to a double-throw switch, which when thrown in one direction will give the full speed, and in the other direction will give the half-speed. This switch can be controlled either mechanically or electrically to regulate the speed of the motor to suit the demand. This arrangement is as simple, or even simpler, than any direct-current device to give corresponding changes in speed.

A modified form of this speed-changing device can be used on squirrel-cage motors employed to drive machine tools and punching and shearing machines, where different speeds are required, and in this case the switch, which changes the grouping of the coils in the motor, is operated by hand.

As an example—a 10-H.P. motor is used to drive a punching and shearing machine. For very heavy work the motor is required to operate at about 75 per cent. of the speed at which lighter work could be done. To meet this requirement, the tappings for the grouping of the coils should be so arranged as to give three-quarter or full speed. If half-speed and full speed are required, the tappings could be arranged accordingly.

The output of the motor is varied in direct proportion to the change in speed, *i.e.*, a 100-H.P. motor at 480 r.p.m. will give

75 H.P. @ 360 r.p.m., and
50 H.P. @ 240 r.p.m.,

but the efficiency at any of these speeds is as high as it is possible to obtain within a very small percentage. As the power required to drive most machinery varies directly as the speed at which it is driven, the output of the motor corresponds very nicely with what is required of it.

The foregoing examples all deal with classes of work where certain fixed speeds will meet the requirements, and all that is necessary is the gradual acceleration between the fixed speeds, but there are other classes of work where it is necessary for the motors to have a speed variation of perhaps six or eight to one, with the possibility of being able to run continuously, and with high efficiency, at any intermediate speed.

This requirement is principally found in connection with paper-making machinery, and in some cases with calico printing, bleaching and dyeing.

The only electrical apparatus which can accomplish this result has until recently been the shunt-wound, direct-current motor operating on two or more voltages, so as to give the required range of speed. The direct-current apparatus for this purpose has always been more or less expensive, and difficult to design.

The single-phase series motor offers a method of accomplishing this result which is simpler and more efficient. The apparatus for this purpose will consist of a single-phase motor controlled by an induction regulator, which is a boosting transformer placed in series with the motor. This regulator or transformer raises or lowers the voltage, depending on the relative position of the primary, which is moved in relation to the secondary by means of a worm wheel and worm.

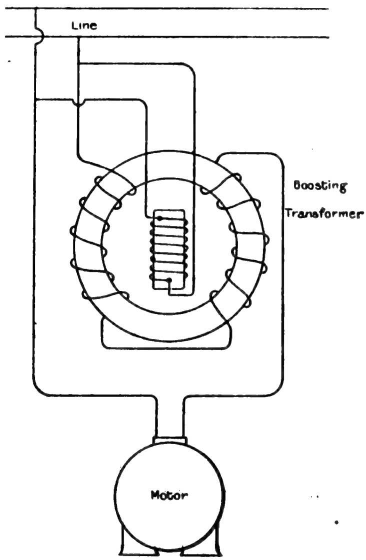


FIG. 6.

Fig. 6 shows this arrangement diagrammatically. Any required voltage from zero to full line pressure can be applied to the motor, and consequently any required speed can be obtained. The losses in the induction regulators are simply the magnetisation and C^2R losses.

It will thus be seen that the arrangement is not only very efficient, but provides for a range of speed variation in fine shades which cannot

be approached by any continuous-current device, unless it be very elaborate and costly.

For variable-speed work, where constant stopping, reversing, and starting again is required, both the squirrel-cage motor and the slip-ring motor may be used.

With the former, the control is effected by applying different voltages to the primary by means of auto-transformers and a controller. For this service the resistance in the secondary should be increased so that the maximum torque is obtained at zero speed. This is accomplished by constructing the end rings, to which the bar windings are bolted, of metal having a higher resistance than that used in the construction of the constant-speed, squirrel-cage motor. The torque of this motor varies as the square of the E.M.F. applied to the primary. This applies to the torque at all speeds, *i.e.*—

E.M.F. = 100 per cent. Torque = 100 per cent.
E.M.F. = 90 per cent. Torque = 81 per cent.
E.M.F. = 80 per cent. Torque = 64 per cent.

and so on.

By means of the auto-transformers and the controller, any voltage can be applied so as to give the required torque and speed.

With the slip-ring motor, the control is effected by varying the resistances in the secondary circuit of the motor, and this method of control corresponds to inserting resistances in the armature circuit of a shunt-wound motor.

For overhead travelling crane work, the squirrel-cage motor possesses some advantages over the slip-ring type, in that three wires only need be led to each motor, and if three motors are used on the crane, one wire may be common to all three motors. Again, one set of auto-transformers can be used in conjunction with the three controllers for the control of the three motors, provided the capacity of these auto-transformers is equal to the maximum demand which will be made by the three motors.

For operating winches, live rolls, and work of this class, the slip-ring motor is preferable for the reason that, in the first place, the starting currents are not so heavy, and in the second place, the currents handled by the controller are all in the secondary circuit, and consequently at a low pressure, which results in less burning of the contacts.

Efficiency and Power Factor.—The importance of high efficiency in any class of motor is pretty well understood, and it may be taken that the efficiency of polyphase induction motors corresponds very closely to the best results obtained with direct-current motors.

The power factor is not generally understood, and is of very considerable importance, particularly in relation to the generating plant.

The total current taken by an induction motor is composed of two elements:—

First, the working current, which performs useful work, and varies in proportion to the actual output of the motor.

Second, the magnetising current, which is at right angles to the working current, and performs no useful work.

The total current which is indicated by an ammeter can be represented as the hypotenuse of a right-angled triangle, of which the other two sides are the working current and the magnetising current respectively.

The power factor is the ratio of the true power to the apparent power expended, as shown by an ammeter and voltmeter.

It will be noted from Fig. 7 that the magnetising current has a large effect on the total current at light loads and a small effect at heavy loads; consequently the power factor is high at heavy loads and low at light loads.

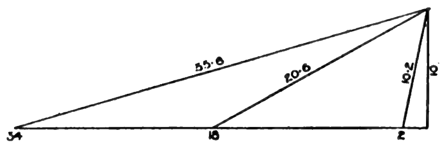


FIG. 7.

The magnetising current, as already explained, is at right angles to the working current, and lags behind it. The lagging current is the one which has an injurious effect on the regulation of the generator, transmission lines, or transformers. The reason for this can be explained as follows:—

If the current is in phase with the E.M.F., the maximum current occurs when the armature coils of the generator are midway between the field poles and the magnetic lines extend between the field poles, and neither increase nor decrease the magnetisation from the field. If the current lags 90°, the maximum value will occur when the armature coils are directly in front of the field poles, and the magnetisation will be decreased as the direction of the armature current will be opposite to that of the field current.

The magnetising current, which is at right angles to the working current, lags 90°, and consequently decreases the magnetisation of the fields, and lowers the voltage of the generator.

It is important, therefore, to maintain the power factor as high as possible.

The chief cause leading to low power factor is generally found to be the use of a number of motors lightly loaded, in which case the lagging current is large in relation to the total current, with a corresponding demagnetising effect on the generating plant.

The fault frequently lies also in inferior design, and when it is borne in mind that the lagging current performs no useful work, and that it has as much effect in heating the cables, transformers, generators, etc., as the working current, the importance of reducing it to a minimum will be fully appreciated.

From the standpoint of the user, the alternating-current apparatus is probably the cheapest both in first cost and maintenance.

The engineer whose experience has been limited to the use of direct-current machines is apt to be puzzled by lagging and leading currents, power factor, frequency, and things of this sort which are not associated with direct-current practice, and argues that any machinery in connec-

tion with which such strange terms are used must of necessity be complicated.

The design is more complex, the planning of a new installation calls for one or two more considerations than with direct current, but the actual operation and maintenance of the plant once installed is simpler and cheaper.

DISCUSSION.

The Chairman.

The CHAIRMAN: I am sure that this paper is one which should lead to considerable discussion. I may say that I am particularly interested and surprised to find it so clearly stated that the cost as well as the efficiency of the alternating-current motor is as favourable, if not more so, than the direct-current motor. It has been, I think, currently believed that the cost of the alternating-current motor is one of the principal objections to it, but here it is stated by the author that the cost in the case of the paper machinery is not greater than a similar plant with direct-current motors. There are also several instances quoted of conditions under which we have all been accustomed to think that the direct-current motor was the only possible means of doing certain work, and I believe it has been advocated by many people that particularly the extreme variation of speed required for paper-making plant was only possible by direct-current motors. Mr. Ionides has certainly stated a case for the alternating-current motor.

Mr. Mavor.

Mr. H. A. MAVOR: Broadly speaking, I think there can be no doubt that the points that Mr. Ionides has raised are nearly all such as we can subscribe to. There is no doubt that to any one who has taken an interest in the development of electrical work the alternating-current has from the very beginning been the more attractive medium, though the development of alternating-current work has been in connection principally with polyphase motors. But I think that it is possible in discussing this matter to strain arguments rather in favour of polyphase work. What the author says about the apparent difficulties on the face of the subject is quite true. These difficulties are in the designing-room and in the drawing-office, and not in the factory nor in the place of operation of the motors. At the same time speed control of polyphase motors is not a straightforward and simple thing. One is tied down to multiples of speed and to specific speeds much more closely than with the continuous current, which is very clearly handicapped by the arrangements in factories where polyphase machinery is being made. I think one could safely say that in all factories where polyphase machinery is being manufactured and turned out in quantities continuous-current motors are still used for a large number of purposes just because they are found more convenient, and easier to apply to a large number of details than polyphase motors. There is no doubt whatever that from the manufacturer's point of view the three-phase motor is the most attractive kind of subject; at the same time one finds that it is not so attractive when you come to deal with all the applications of it. The author, at the beginning of the paper, very

properly calls attention to the presence of electrical distribution companies as a very important element in the question. If we can get our current cheaper than a three-phase current we will certainly use it, but if, on the other hand, this three-phase arrangement be only a temporary one, then we need not trouble to go into the refinements of design which are necessary to apply polyphase motors to all the details of industrial mechanism. It is, on the whole, likely that the supply companies will be able, before long, to give us a single-phase alternating-current, and it will do all that we require. Mr. Ionides has made no reference to perhaps the most important part of this possible work for the supply companies, and one which all of us look upon with great interest as likely to lead the way, as it has done in America, in all the methods of power generation and distribution—I mean the use of electricity for traction. If the experiments now being carried out in America in single-phase traction offer inducements to people on this side to adopt these means, it will lead to a very interesting simplification of the problem. At the present moment we cannot feel that the arrangement in use in Glasgow, for example, can be a permanent solution of the problem, namely, that the current generated is a three-phase current and then a transformed and continuous-current. Mr. Mavor.

Mr. H. B. MAXWELL: I do not suppose there is any class of work where polyphase motors would show to such advantage as in shipyard work—it is such rough and tumble work, and they are subjected to very severe treatment. To my mind the three-phase induction motor is most useful for extremes; I mean to say, that for fixed speed work there is nothing to compete in every respect with the polyphase induction motor, and also in the other extreme, such as printing machinery and even calenders and paper-making machinery. I do not say that the complications required by the polyphase system are any more serious than in the electric current, but in the D.C. system any one who has seen this process knows that the complications are quite as severe. There is not the slightest doubt that for work such as cranes, hoists, and even lathes and other tools where machines are required to run at varied speeds for long periods, a polyphase motor cannot compete in any way with the D.C. motor owing to this speed regulation. With reference to the method of varying speeds (Fig. 5) by the alteration of the poles, the author explained that with the three-quarter speed three-quarter power is also obtained, but I fail to see that in punching and in drilling machines when working at a much higher speed with lighter work, the amount of work that the motor has to do will be in proportion as a matter of fact to the speed. Fig. 6 seems to me to illustrate a much better method of speed variation from the stationary point of view, as the power factor must be particularly low. The squirrel-cage or the polyphase induction motor is no doubt an excellent motor to be handled by ordinary rough labour, owing to the absence of the commutator, but as regards the single-phase motor in a section like this, it appears to be somewhat of a dark horse, since nobody apparently seems to know anything about its capabilities or its characteristics. Mr. Maxwell.

Mr. Spence. Mr. W. R. SPENCE: The author suggests the means of starting induction motors which may possibly be just workable on a very low voltage installation, and I think if there is anything to guard against more than another it must be to avoid starting by running up slowly, otherwise disturbances occur on your line voltages such as will injure any motor. By that method it may be practicable when a very low voltage installation would be impracticable. After all, the voltages in my own experience, giving 2,000 revolutions, are the voltages with direct machines by bringing all the motors on the line of starting them slowly. If we are to believe the statement in the paper the A.C. motor is the only motor that is possible with the modern development. Personally, I have had a little experience with these, and I can assure the author that direct-current motors of 1,400 revolutions are absolutely satisfactory, and they have the advantage which the A.C. motors have on the paper, but not when you get them down to the ground level, at which you can vary the speed to meet the requirements. I would ask if, when you stop the three-phase motor, do you always leave the starter on the line? If so, it is peculiar. It is stated that a three-phase plant costs no more than a direct-current. I have no doubt that that must have reference to manufacturing costs, but I do not know about that. I do know certainly that the cost to the purchaser is very different. If you buy single motors you are all right, but when you come to a system as shown in Fig. 5 you find that the direct-current system costs very much less, and, as a previous speaker has pointed out, when you do get an alternating-current plant put into factories you will find also all the advocates of alternating current putting down direct-current plant for the different requirements. Where that is done you will find the friction discs to give you a variable speed. I should like to know if the author considered the punching and shearing machines with heavy fly-wheels to be constant speed machines suitable for squirrel-cage or polyphase motors. Personally I consider that punching and shearing machines should not be driven by a motor, but by a flywheel and the motor should only be used as a means for keeping them going.

Mr. Hird. Mr. W. B. HIRD: I was very much pleased and to a certain extent surprised to find that Mr. Ionides praised as much as he did the squirrel-cage motor as contrasted with the slip-ring motor. It certainly struck me as I heard the paper read that he was claiming for the squirrel-cage more than I thought could be obtained from it. I should like to ask Mr. Ionides if he can tell us what his estimate would be of the efficiency and of the slip under normal conditions of a squirrel-cage motor which was capable of starting with a torque equivalent to a full load, and taking only two and a half times to do this, and also what would be his estimate on the same point for a squirrel-cage motor, which was designed in the way he mentions if a motor was wound to give its maximum torque at standstill. Again, another thing which I think has been over-rated perhaps in the slip-ring motor is the ease with which variable speed is obtained from it, for there is no doubt that a speed at the ratio of two to one or three to one which may be desired, can be obtained by throwing over so as to alter

the number of torques, it is nevertheless the case that the property of the motor as to torque and efficiency must be very badly sacrificed either by making a compromise or by winding the motors at one speed only, and sacrificing it when the throw-over is made to the other speed. In spite of all this I quite agree with Mr. Ionides' remark that the question of speed variation such as can be obtained from a shunt motor is very much exaggerated in all associations where alternating-currents are brought in and the number of cases where a simple shunt control can give you what you want is extremely limited. In the cases where they are necessary, no doubt a shunt motor is the right thing, but the number of cases where such control is required is not nearly as many as may be made out by the advocates of direct-currents as against alternating-currents. Mr. Hird.

Dr. J. BLACKLOCK HENDERSON: I agree with the author in considering the asynchronous motor ideal for the large majority of cases in workshop practice, and if all the members here had visited the works in the Newcastle district last month with the University Engineering Society, they could not fail to come to the same conclusion. There the one power supply company supplied 3-phase power at a cheap rate, and the result is that almost all the works in the district take their power from the company. One point that struck me in going through these works was the inaccessible positions in which most of the motors were placed. As a rule they were bolted to the roof joists, or high up on the vertical columns, and this alone speaks volumes for the reliability of the asynchronous motor as a machine. Dr. Blacklock Henderson.

Some speakers object to the low power factor of the motors, but the consumer need not concern himself with the wattless current, as he pays nothing for it. By arranging with customers here and there for the installation of synchronous or compensated asynchronous motors or of rotary convertors and properly exciting them the supplier has complete control of the power-factor in each district. Rotary convertors or motor generators are necessary for many purposes at any rate, as in the Newcastle district for the North Eastern Railway, and by means of these the station engineer can relieve the generators of the wattless current; but this does not concern the consumer in any way. The author remarks, on p. 477, that "at no load the rotor will revolve at the same speed as the magnetic field." This will only be the case for the ideal frictionless motor, actual motors having a slip of a fraction of 1 per cent. when running light. In connection with the relationship between starting torque, current, efficiency, etc., it would have been much more instructive if Mr. Ionides had shown the relationship which exists between these by means of the Heyland diagram. Mr. Spence has objected to the method described in the paper of starting all the machinery in a mill simultaneously by starting the engine after exciting the generator, because of the unknown rise of voltage in the circuits due to resonance. The danger from this cause must be quite negligible on account of the very small capacity and the high self-induction in the distribution system in a mill. Even if resonance were possible, the voltage attained would amount to only

Dr. Blacklock Henderson.

two or three times the normal voltage, but that would not be dangerous to any insulation. In Mr. Field's experiments on resonance in the Glasgow tramway distribution system resonance was only detected in any considerable amounts when the generators were running light coupled to several miles of cables, and never when running on load. The compensated series motors have not been mentioned at any length by Mr. Ionides, and they could easily form the subject of a separate paper. The object of compensation is not entirely the improvement of the commutation of these motors (p. 478), but also the reduction of the effects due to armature self-induction and armature reaction.

Mr. Stevenson.

Mr. GEORGE STEVENSON: With your permission I should like to make one or two remarks as a user of motors. I am in the unfortunate position of having fourteen or fifteen motors to look after, and I consider that I am in a fairly good position to know the conditions with regard to direct-current. My experience has been that with the very best direct-current you have most trouble. There is not only the tear and wear in the renewal process, but also in the course of three or four years the commutators, and also the windings, become filled up with copper dust, and especially in mining work they get filled up with coal dust, and that gives trouble. The commutators have to be taken out. I think, for constant speed work, there is nothing to beat the 3-phase squirrel-cage motor. I have been making a few inquiries in that direction, and I understand that the slip-ring motor is just as troublesome as any other. There is one thing that Mr. Ionides has not referred to, and that is that instead of employing an auto-starter it is possible to arrange the motor so that you can change the connections. A fast and loose pulley is a very much simpler arrangement than an auto-starter. In a direct current it is generally accepted that in the majority of cases the trouble is due to the starter. It is advisable not to get rid of the commutator. There was one other point referred to by the speakers in connection with the Heyland turbine pumps, and that was the question of speed regulation. In that case it is not necessary to have speed regulation. We can obtain the same results by putting in a sluice valve, by which the amount of the work can be limited which the pump has to do, and the motor can be run at constant speed. For that work the polyphase motor is the best thing to put in. Another remark was made in connection with the speeds of polyphase plant, but I think the polyphase motor is suitable for extremely high speed, but not for a low speed. The efficiency of the motor is very much greater at high speeds than at low speeds, and in laying out a 3-phase plant that is an important thing to keep in view—to keep them running at a high speed.

Mr. Ionides.

Mr. IONIDES (*in reply*): The single-phase series motor was referred to by Mr. Mavor as a possible means of doing away with polyphase motors, but I cannot say that I agree with him in that. The single-phase motor seems to have its own particular field just as the direct-current motor has at the present time, and if one can construct a motor of the squirrel-cage type, without commutator or slip rings, that is something to stick to till you get one without bearings. Mr. Mavor

Mr. Ionides.

also referred to the future of the single-phase motors for electric traction, and I think there is little doubt that single-phase motors have a great future for that purpose, particularly for suburban traffic, not so much for local traffic such as one has in the congested part of a city, but where high power can be used, and where the traffic is not sufficient to pay for subsidies. This paper was intended simply to deal with the subject from the standpoint of industrial work, and electric traction is a thing that is so big that I cannot enter into it very far. In shipyard work Mr. Maxwell says that the squirrel-cage motor has its own particular field, and I very cordially concur with him. I think that a great many people laying out a new plant are apt to consider in a few cases the variable speed requirement as against the great majority of constant speed motors required, and the result is that the variable speed motors are in his mind when he is laying out a scheme, and he forgets that thirty-five of them may run at a constant speed, and the loss of efficiency is very small. There is a loss in power compared with the greater loss in the direct-current in maintaining high efficiency. I have seen the three-phase motors of 20-horse power started straight up, and the man forgets that it is worth while going out of his way to use the three-phase induction motor. In some cases in the United States they go so far as to shut down an alternating-current and then have rotary converters for their cranes, and where the load is sufficiently big that is probably a good thing to do. Mr. Hird made some remarks on the subject of efficiency and slip, and Dr. Henderson, in a manner, described these features of the squirrel-cage a good deal more ably than I could do. Mr. Spence is an acknowledged direct-current advocate, and I cannot hope to see him take the same view of things as I do, but he referred to a remark in the paper in regard to spinning machinery by connecting them straight on and running them up with an engine. I have known that done continually without having any harmful results, and, as he says, the voltage does rise a good height, but in the average industrial plant one does not use more than 400 volts, and if you are receiving it is obvious that you cannot start in that way. With regard to building 80 horse-power motors at 400 r.p.m., it is not a thing that any manufacturer wants to do, and the squirrel-cage motor shows a way out of the difficulty. In regard to slip-ring control, Mr. Spence wanted to know what happened to the primary circuits, and whether they were left closed. Of course they are not, they are open; but at the time they are open the existence of the secondary circuit is usually such as to make the current primary, and with the reversing motor used for starting and stopping it is usually the case, and you can open-circuit your secondary before you can open-circuit your primary. In regard to the first cost, as to the alternating and direct-current, the one can be made more or less expensive according to choice, but in actual practice, when it comes to working out the two plants side by side, the one for alternating-current and the other for direct-current, the induction motor is cheaper of itself, and with the type of starter you cheapen the thing, but, on the other hand, your generator must have an exciter.

Mr. Ionides. It is very much cheaper to put in alternating-current motors. Mr. Stevenson spoke of direct-current giving trouble in course of time, but I think that is a thing that probably the most of us have an experience of. He has referred to a starting method of induction motors with which I am not familiar, and speaking off-hand, I am not sufficiently of a designer. That is the group of coils so as to give about 50 per cent. of E.M.F. in starting. The two-phase motor would be simple, because it would give 70 per cent. on my line pressure, which would give full load torque. As to the question of efficiency at high speeds, the whole question of efficiency in induction motors is not so much a question of speed, but air-gap in the shape of slots, and a variety of things of that sort about which I cannot speak with great knowledge, but it is not so much a question of high speed, because these low-speed motors can be built with as good efficiency as high-speed motors. One further point one speaker made was in connection with the arrangement of two speeds. The efficiency must be very bad at one speed if it was good at the other. I can only speak from the results in this connection, that the efficiency at the half speed is almost as high as at full speed. If you take a standard frame not provided for such variations you may get fair results.

The Chairman. The CHAIRMAN: I have very great pleasure in asking you to accord to Mr. Ionides a very hearty vote of thanks for his paper. I think that we are particularly indebted to him, as he is not a member of the Institution, but comes to us as a visitor to give his paper.

The vote of thanks was carried by acclamation.

E.M.F. WAVE FORMS.

By E. A. BIEDERMANN, Student, and J. B. SPARKS, Student.

(*Abstract of Paper read before the Students' Section, May* 24, 1905.)

The first part of the paper deals with the most economical shape of wave for the operation of any one piece of apparatus for the consumption or transmission of electrical energy, and points out that, in by far the majority of cases, the pure sine wave of E.M.F. is the best.

In the second part, the factors determining the form of E.M.F. wave are considered. These factors were discussed under two heads: (1) Distribution of Flux; and (2) Distribution of Winding.

(1) *Distribution of Flux.*—The effect of the teeth in producing ripples on the flux wave was shown from curves obtained experimentally, and different methods for obtaining suitable flux distribution in the gap were given, E.M.F. and flux curves relating to these methods being shown. The influence of the ratio $\frac{\text{pole arc}}{\text{pole pitch}}$ was then considered, and it was shown that by taking suitable values of the ratio, it is possible nearly to eliminate certain harmonics from the flux curve.

Although shaping of the pole shoe may result in a good E.M.F. wave at no load, yet, when current is being taken from the machine, the effect of armature reactions has to be reckoned with. The effect of the reaction is to crowd the flux to the trailing end of the pole. This effect is illustrated in the following figures:—Fig. 1 shows the flux distribution and E.M.F. curve at no-load for a 3-phase machine, having a pole only slightly rounded at the edges and four slots per pole per phase. The dotted curve in Fig. 2 shows the reluctance of the magnetic paths at different points along the gap. The lines representing the flux density in Fig. 1 were drawn in inverse proportion to the vertical ordinates of this curve. Fig. 3 shows the flux distribution due to the reaction of the armature coils alone. In this diagram the reactive-ampere turns per pole have been reckoned as one-third of those on the field-magnet per pole. In order to show the distribution better, two lines have been drawn, for one in the first and fourth diagrams, due regard being paid to this fact in combining the first and third diagrams to produce the resultant distribution shown in Fig. 4. The flux distribution due to reactions alone, shown in Fig. 3, was obtained in the following manner:—

The full-line curve in Fig. 2 represents the magneto-motive force due

to the armature coils at different points along the gap. As before mentioned the dotted line represents the reluctance of the air-paths at different points, so that in order to obtain the flux distribution it is only necessary to divide the ordinates of the full-line curve by those of the dotted curve. The result of this division is shown in the chain-dotted curve, from which the lines representing flux distribution in Fig. 3 were drawn in. The reluctance curve, however, does not take into account the increased reluctance of the air-paths at the points where the slots occur. In drawing in the lines in Fig. 3, allowance was made for this effect, the result being that the curve in Fig. 3 does not show the sharp corners seen in the chain-dotted curve in Fig. 2. In plotting the M.M.F. curve in Fig. 2, the average reaction effect was assumed, another assumption being that the current follows a sine law

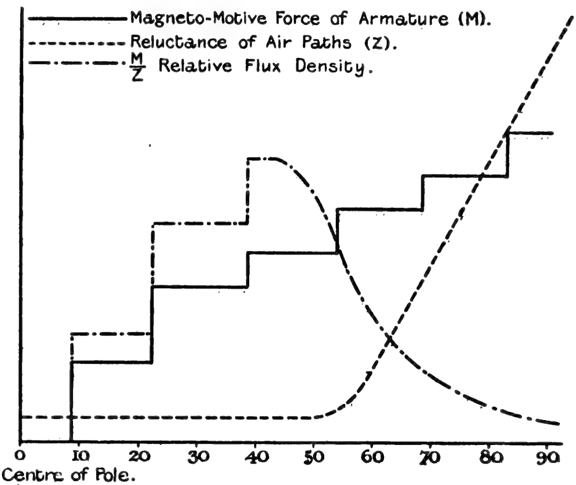
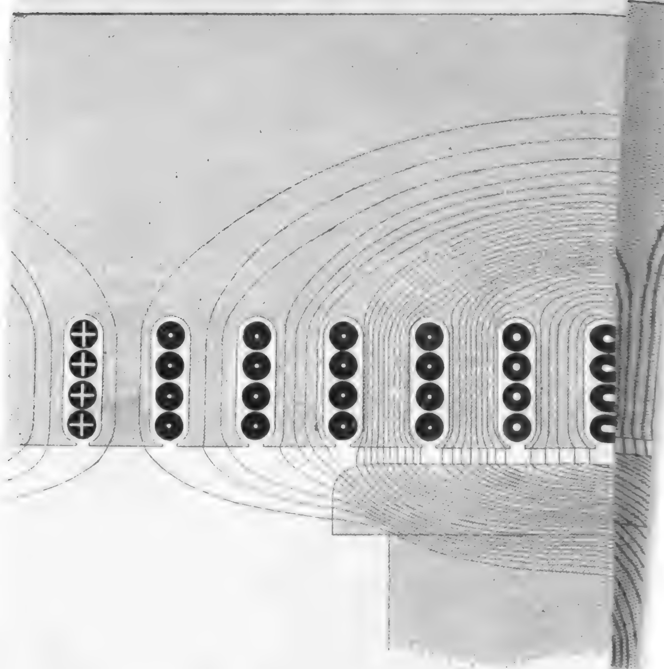
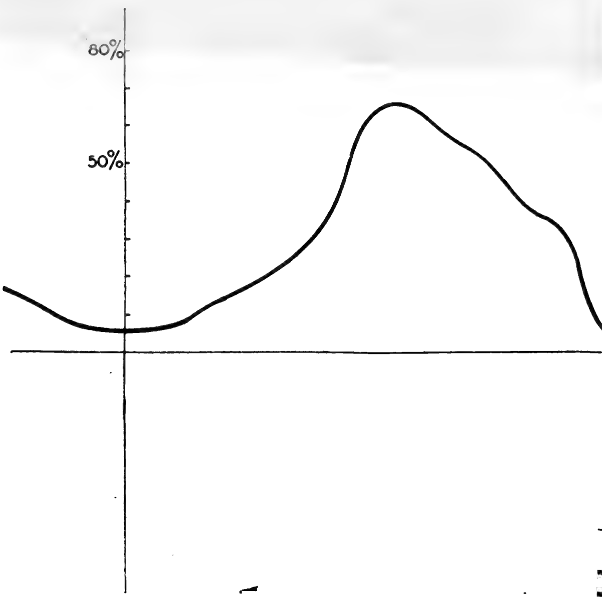


FIG. 2.

and is in phase with the E.M.F. Fig. 4 is the result of combining Fig. 1 and Fig. 3, and shows the distortive effect of the reactions.

The result thus theoretically obtained was also investigated experimentally. The experiments were carried out on a model of an alternator having two closed slots per pole per phase. The method employed was as follows:—A narrow search-coil, of the full length of the armature (1·25″), was placed in the gap and two readings of the ballistic galvanometer, to which it was connected, were taken for each position of the coil. The first reading was taken on breaking the exciting current, the second on making in the reverse direction, the mean of these being therefore proportional to the flux density in the gap. Readings were taken every five degrees along the gap. Great difficulty was experienced in making a search-coil sufficiently narrow and thin (the length of the gap being only 0·06″), at the same time

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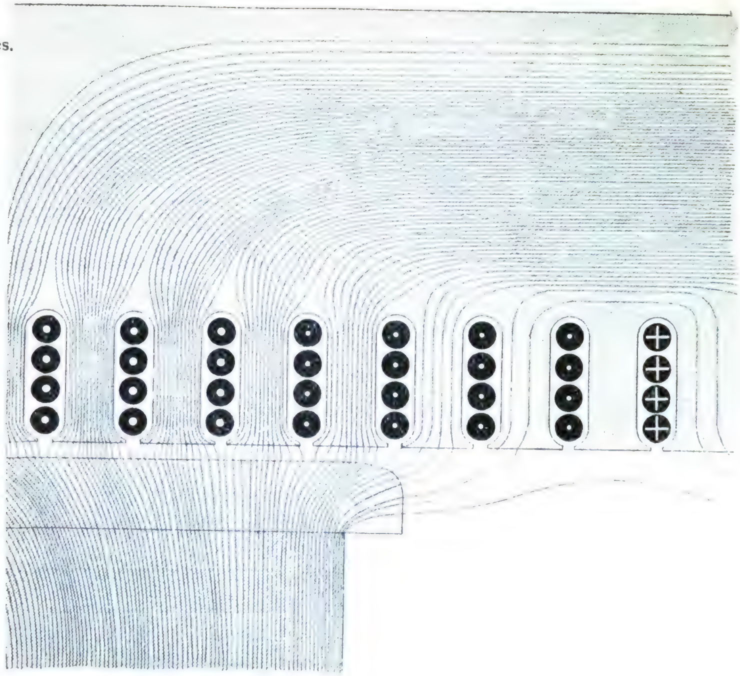
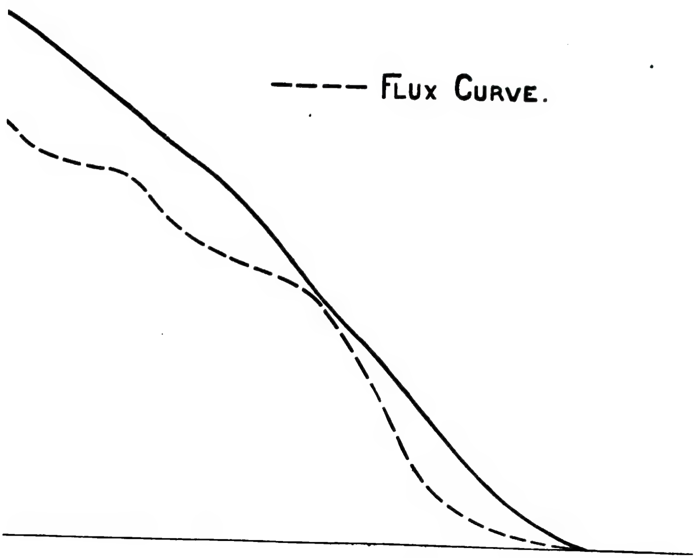
Mr. Ionides.



The Chairman.



URVE.

FIG. 4.

having sufficient number of turns to cause a large enough deflection of the galvanometer.

After several trials to find a suitable form of search-coil, one was made in the following manner. A narrow slit about 3·5 millimetres wide, and of the same length as the thickness of the iron core, was made in a piece of cardboard about six inches long, and of a thickness slightly less than the gap. In this slit was imbedded a narrow coil consisting of 15 turns of No. 40 S.W.G. copper wire. To measure the exact area enclosed by this coil the whole apparatus was laid down on a photographic plate, and exposed to Röntgen rays, so that a radiograph of the exact size was obtained.

The coil was protected on both sides by a thin piece of mica let into the cardboard, the outside width of the coil being rather under 0·1 inch. The coil was let in at right angles to the length of the cardboard, and the latter was placed in the gap, and moved as required, round the periphery of the armature. In this manner the coil was always moved perfectly parallel to itself, which was of course most necessary in order to obtain the true distribution of the flux. The coil being thus entirely hidden in the cardboard, it was necessary to take a radiograph of it, in order to show the exact size and shape.

The results of these experiments are shown in Figs. 5 and 6. The full-line curve in Fig. 5 corresponds to the no-load distribution as in Fig. 1. Fig. 6 corresponds to Fig. 3, and the chain-dotted curve in Fig. 5 corresponds to the full-load case shown in Fig. 4. In the experiment from which Fig. 6 is plotted, the armature current had a lead of about 15°, thus accounting for the unsymmetrical shape of the curve.

Considering this, and also the fact that there were only two slots per pole per phase, compared with four in the case of Fig. 3, it will be seen that the experimental result bears out very closely that obtained theoretically.

The effect of the reactions is much more pronounced with a single-phase than with two- or three-phase machines, because in the first case the magneto-motive force due to the armature coils is simply alternating, while in the latter cases the resultant magneto-motive force is rotating, though not necessarily at uniform speed, or at constant value. Still, it does to all practical purposes follow the main flux round. In consideration of this, it is obvious, that if it were possible to produce a sine flux distribution due to the reactions alone, since it is a comparatively easy matter to produce a sine distribution of the main flux, the two together would also give a resultant sine distribution, and this would be so whether the load were large or small, inductive or non-inductive. The difficulty of doing this decreases with the inductiveness of the load. On a fully inductive load, the above may actually happen in an ordinary type of three-phase generator, but with a purely non-inductive load the difficulty is very great indeed. On such a load the magneto-motive force due to the armature is bound to be distributed in such a way that its maximum effect occurs midway between the poles. Now, referring to the dotted curve in Fig. 2

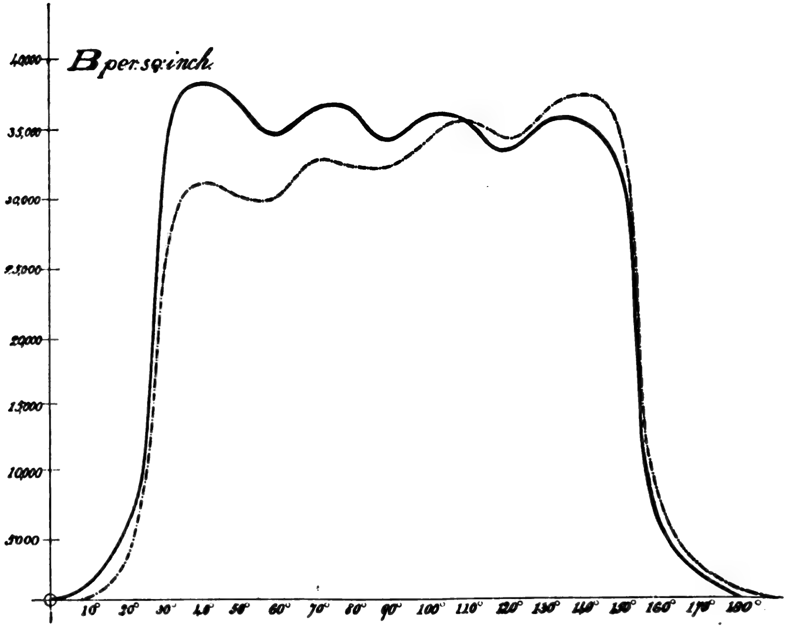

B per sq. inch.
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5000
10° 20° 30° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140° 150° 160° 170° 180°

FIG. 5.

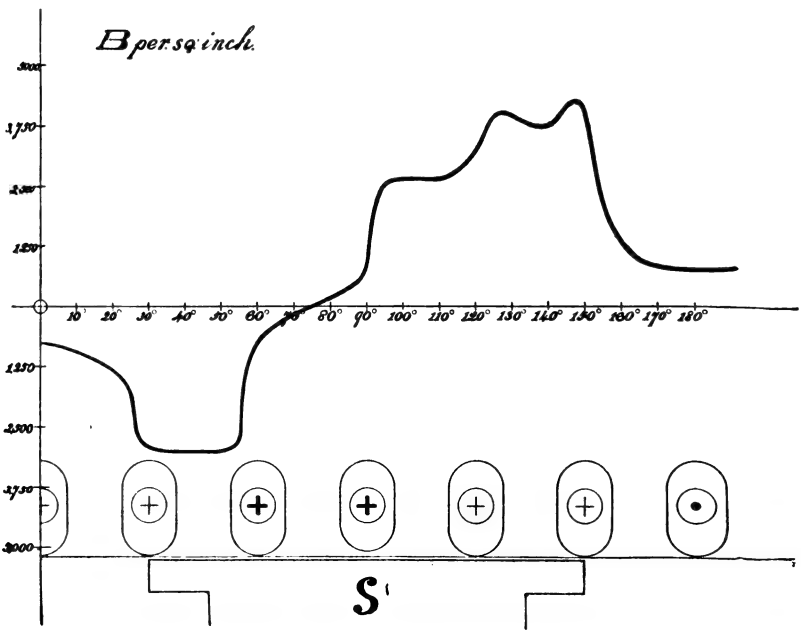

B per sq. inch.
3,750
1,250
10° 20° 30° 40° 50° 60° 70° 80° 90° 100° 110° 120° 130° 140° 150° 160° 170° 180°
1,250
2,500
3,750
S

FIG. 6.

showing reluctance of paths, it will be seen that their reluctance increases rapidly from the pole tips, rising to a maximum midway between the poles. Consequently the flux density cannot possibly be at its maximum at this point, but on the contrary, as shown in both curves depicting flux distribution due to reaction alone, it falls nearly to zero.

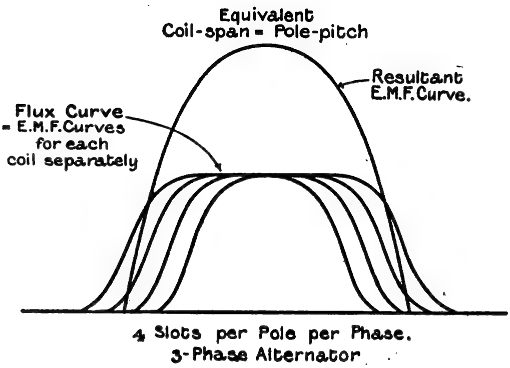


FIG. 7.

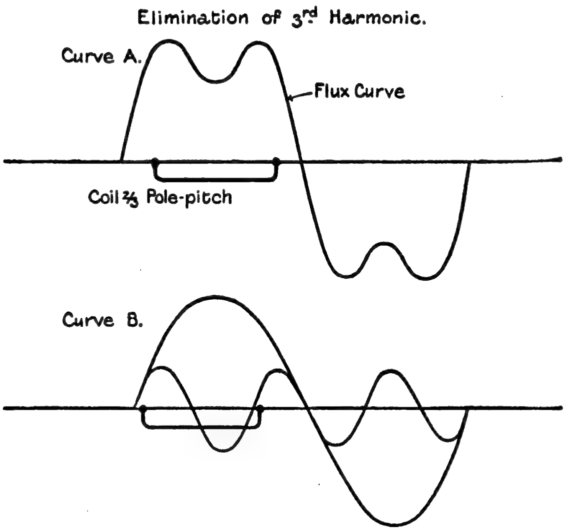


FIG. 8.

This shows that it is next to impossible for the distribution produced by the armature coils alone to be of a sine form. If, however, the exciting coils, instead of being wound on projecting poles, were wound in slots in a smooth rotor, the difficulty of the great variation of

reluctance would be overcome. This has actually been done in the case of several turbo-alternators.

Distribution of Winding.—There are several reasons for distributing the winding, most of which bear either directly or indirectly on the E.M.F. wave form. With very large slots, whether open, closed, or partially closed, the flux will concentrate directly under the teeth, the disadvantages of which have been already pointed out. Also the

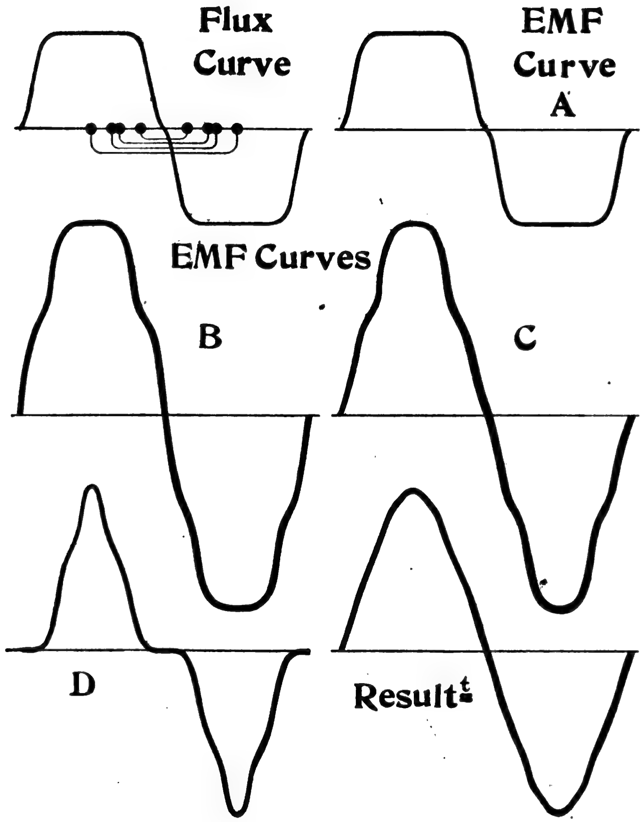


FIG. 9.

magneto-motive force due to the armature current in a concentrated winding, being concentrated over the area covered by one coil, will naturally affect the wave form to a greater extent than if the winding were spread out. If the winding is distributed, and the coils wound in equally-spaced slots, the E.M.F. curve will be the sum of several E.M.F. curves, of a form identical with that of the flux curve, displaced from one another a distance equal to the slot pitch. This has the effect of producing a fair approximation to a sine E.M.F. curve from a com-

paratively flat-topped flux curve, as can be seen in Fig. 7, which is drawn for a four slot per pole per phase machine.

Besides this general improvement of the curve, it is possible to arrange the span of a coil, so that any desired harmonic shall be eliminated. Curve A in Fig. 8 represents a flux curve with a pro-

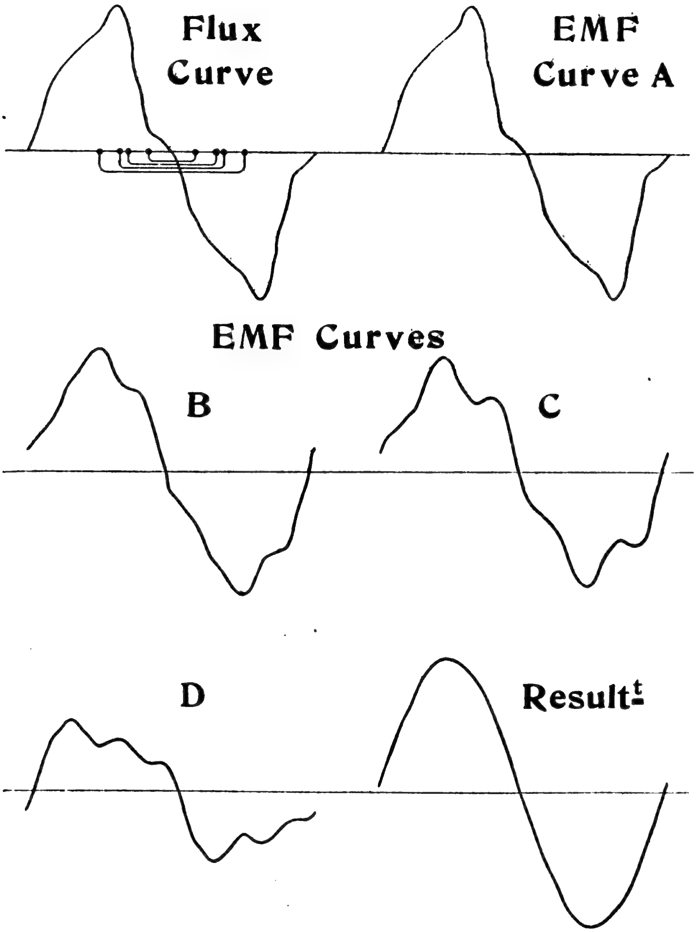


FIG. 10.

nounced third harmonic. Such a harmonic is very unlikely to be eliminated by an ordinary winding, but by making the span of the coil two-thirds the pole-pitch, the third harmonic will entirely disappear in the E.M.F. curve. The reason for this can be easily seen by looking at the analysed curve shown below in Fig. 8. Consider only the E.M.F. induced by the cutting of that part of the flux represented by the third

harmonic. The two sets of conductors which the coil comprises are at every instant in a field of the same strength and sign, and since the resultant E.M.F. is equal to the difference of the E.M.F.'s in the two sets of conductors, it will at every instant be zero. The E.M.F. induced by the conductors cutting that part of the flux represented by the fundamental will necessarily be of a sine form, though its maximum value will only be 0·866 of that which would have been generated by a coil spanning a pole-pitch.

Though this is only a simple case of elimination, Professor Rüdenberg* has shown that it is possible to eliminate any two harmonics with two coils or any three harmonics with four coils. He also showed that three harmonics can be eliminated with three coils, but the solutions of the equations, to obtain the necessary widths of coils, are only capable of a graphic solution by trial.

In the same way it would also be possible to eliminate any given number of harmonics (and their multiples) by that given number of coils, but the difficulty of even the graphical solution becomes enormously increased. The general formulæ for obtaining the necessary widths of coils for eliminating two harmonics with two coils, and three harmonics with four coils, are—

$$\text{Two coils}\begin{cases} a_1 = \dfrac{b}{2}\left(\dfrac{p}{m_1} + \dfrac{q}{m_2}\right) \\[2ex] a_2 = \dfrac{b}{2}\left(\dfrac{p}{m_1} - \dfrac{q}{m_2}\right) \end{cases}$$

$$\text{Four coils}\begin{cases} a_1 = \dfrac{b}{2}\left(\dfrac{p}{m_1} + \dfrac{q}{m_2} + \dfrac{r}{m_3}\right) \\[2ex] a_2 = \dfrac{b}{2}\left(\dfrac{p}{m_1} - \dfrac{q}{m_2} + \dfrac{r}{m_3}\right) \\[2ex] a_3 = \dfrac{b}{2}\left(\dfrac{p}{m_1} + \dfrac{q}{m_2} - \dfrac{r}{m_3}\right) \\[2ex] a_4 = \dfrac{b}{2}\left(\dfrac{p}{m_1} - \dfrac{q}{m_2} - \dfrac{r}{m_3}\right) \end{cases}$$

where a_1, a_2, etc., are the half-widths of the coils, $b =$ the pole-pitch, p_1 is any even number, and q and r are any odd numbers.

In Fig. 9 a flat-topped curve has been taken, and coils having respectively half-spans of $\frac{106}{105} \times \frac{b}{2}$, $\frac{76}{105} \times \frac{b}{2}$, $\frac{64}{105} \times \frac{b}{2}$, and $\frac{34}{105} \times \frac{b}{2}$, these being obtained from the formulæ given above.

* *Elektrotechnische Zeitschrift*, vol. 25, p. 252, 1904.

Curves A, B, C, D, are the E.M.F. curves for the four coils respectively, and are obtained by plotting the difference in height of the flux curve, corresponding to the two sides of the coils. The span of the first coil being practically equal to the pole-pitch, the E.M.F. curve is identical in shape with that of the flux curve. The resultant shown

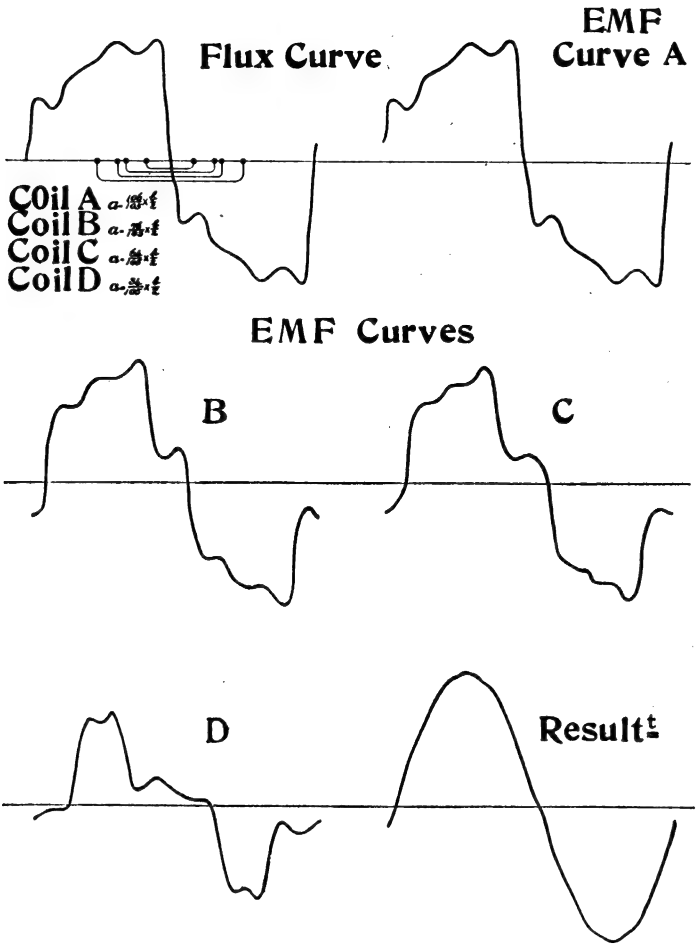


Fig. 11.

below is very nearly a sine wave. This set of coils eliminates entirely the third, fifth, and seventh harmonics, and, of course, any harmonics whose order is a multiple of these. In Fig. 10 the E.M.F. for the same set of coils has been found, when the flux curve is of a form which is produced by the effect of the reaction of the armature. Here again the resultant E.M.F. is very nearly a sine wave.

The flux curve in Fig. 11 is one very likely to be produced at full load in a machine having large open slots. There are evidently some smaller higher harmonics still left in the resultant E.M.F. curve, but the more pronounced harmonics have all been eliminated. To show what can be done in this way, a much more irregular form of curve has been taken to represent the flux distribution (Fig. 12), and the resultant

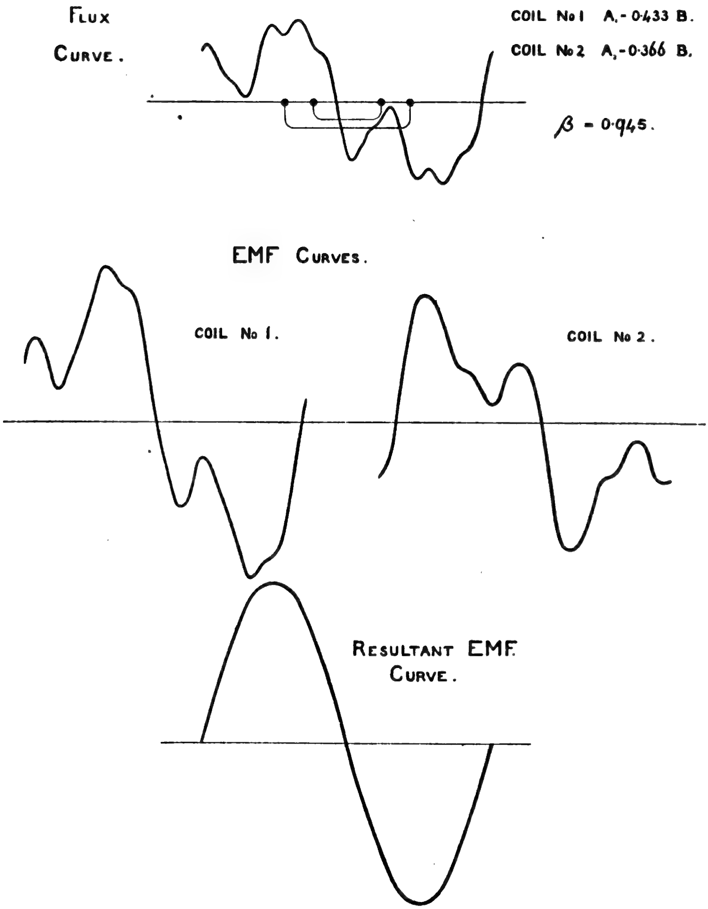


FIG. 12.

E.M.F. curve with only two coils is practically a pure sine wave. From these curves it can be seen that not only on no-load, but on full load or any other load, a constant sine form of E.M.F. can be obtained by the use of such sets of coils. But it must be remembered that their use entails the unequal spacing of slots, thus greatly increasing the cost of the stampings.

In general also, it is impossible to arrange these coils for three- or even two-phase machines, though in special cases this might be done. The set of coils used in the above diagrams constitutes such a case, since it could be used for a three-phase winding, as the conductors of the right-hand side of the coils of one phase come exactly into the same position as those on the left of the coils of the next phase. The conductors of the different phases would in this case be placed in the same slots.

THE PRESENT ELECTRICAL EQUIPMENT OF THE LONDON COUNTY COUNCIL TRAMWAYS.

By J. W. ANSON, Student.

(*Abstract of Paper read before Students' Section, Feb.* 1, 1905.)

I. SYSTEM.

This paper deals with that part of the tramways, owned by the London County Council, in the South of London, which has been reconstructed for electric traction on the conduit system. The total length of the lines so reconstructed amounts to about 56 miles of single track.

Type of Conduit.—The lines are equipped on the open slot conduit system, with the slot in the centre of the two running rails. The yokes, which are used to form the conduit, are similar to the letter U in general shape. They are made of cast iron, weigh 160 lbs. each, and are placed at 3 ft. 9 in. centres. The bodies of the yokes are made to H section.

Slot Rails.—The slot rails are made of steel, weigh 60 lbs. per yard, and are made to Z section. The rails are provided with a drip edge at the bottom side of the head, so that any water finding its way into the slot will fall to the bottom of the conduit clear of the conductor rails.

Track Rails.—The track rails are of the girder type weighing 102 lbs. per yard. The rails are carried on 12 in. concrete, and are secured to the yokes forming the conduit by means of adjustable tie-bars. The track rails are not bonded, as an insulated negative return is used.

Conductor Tees.—These are made of soft steel and weigh 22 lbs. per yard. The sectional area of the tees is 2·15 sq. in. and the guaranteed conductivity is $\frac{1}{7}$ that of copper. The tees are bonded at the joints by two copper bonds having a total cross-sectional area of 0·216 sq. in.

The tees are electrically divided into half-mile sections by means of a 2 ft. gap. Feeder cables, supplying the lines with power, are connected up at such places, and at these 2 ft. gaps the slot is formed by two removable chequered plates. The opening formed when these plates are removed can be used for taking any obstruction from the conduit.

Insulators.—The insulators, which support the conductor tees, are bolted to the bottom of the slot rail, and are fixed at 15 ft. centres. At these points of support, the conduit is widened out and surface boxes fitted in order that an insulator may be taken out, etc. The insulator is

made up of three parts—a cast iron cover with projecting flange, a porcelain petticoat, and a wrought iron stem to which the clip for supporting tee is bolted. The parts of the insulator are cemented together, and are corrugated to give additional strength.

II. Equipment of Generating and Substations.

Pending the completion of the London County Council's Tramway Power Station at Greenwich, which will have an ultimate capacity of about 35,000 k.w., arrangements have had to be made for a temporary supply of current for working the tramways. This has been accomplished in two instances by the erection of steam plant at the generating stations of the London Electric Supply Corporation at Deptford, and the South London Electric Supply Co. at Loughborough Junction, S.E. Steam is suppplied by these companies, and payment is made by the London County Council according to the number of B.O.T. units generated, measured at the switchboards erected by the London County Council. The plant owned by the London County Council at the South London Electricity Supply Co.'s station at Loughborough Junction may be briefly described as follows :—

Engines.—The Council have erected two 1,500 k.w. steam generators. The engines are the cross-compound type, made by Messrs. Ferranti, Ltd., of Hollinwood, Lancashire. The diameter of the H.P. cylinders is 31 in., diameter of L.P. cylinders 62 in., stroke 2 ft. 6 in., and speed 150 r.p.m. The guaranteed steam consumption of these engines on full load is 24 lbs. per kilowatt-hour.

Generators.—The generators are mounted between the two cylinders of the engines, and were made by Messrs. Dick, Kerr & Co., Ltd., of Preston. The machines, which are compound wound, have 12 poles, and are similar in design to the standard machines manufactured by the above firm. The yoke is made of cast iron, and the pole pieces, which are of laminated steel, are cast into the yoke. The armature is of the drum-wound type with lap windings.

The rated full-load output of these generators is 2,400 amperes at 630 volts.

Steam and Exhaust Piping.—The main steam pipes are two in number, one for each engine. The pipes are 12 in. diameter, and are heavily lagged.

The main exhaust pipes from each engine are 22 in. diameter. These exhaust pipes lead to a condenser, which is situated in the main building of the Lighting Company's station.

Switchboard.—The switchboard was supplied and erected by Messrs. Ferranti, Ltd., and is of their cellular type adapted for heavy direct-current work.

There are six panels arranged as follows :—

2 generator panels, 3 feeder panels, and 1 booster panel.

The largest circuit breakers for the generators and feeders are of the horn type.

The ammeters are of the edgewise type, and the scales are marked

to 3,000 amperes for the generators, and 1,200 amperes for the feeders. A bus-bar voltmeter and a paralleling voltmeter, both reading to 700 volts, are fixed to a swinging bracket near the switchboard. The three feeder panels control the outgoing feeders to the three substations at Clapham, Brixton, and the Elephant and Castle.

Feeders.—The feeders to the Brixton and the Elephant and Castle substations are two 0·75 square inch positive cables, and two 0·75 square inch negative cables to each station.

Three 0·75 square inch positive cables, and three 0·75 square inch negative tables connect Loughborough with the Clapham substation.

These main cables were supplied by the British Insulated and Helsby Cables, Ltd., of Prescot; they are paper-insulated and lead-covered.

Substation Low Tension Distributing Equipment.—In each substation one feeder panel is provided for each half-mile of tramway supplied with current from that substation. A combined B.O.T. and testing panel is also fitted in each substation. The number of feeder panels at the various stations are as follows:—

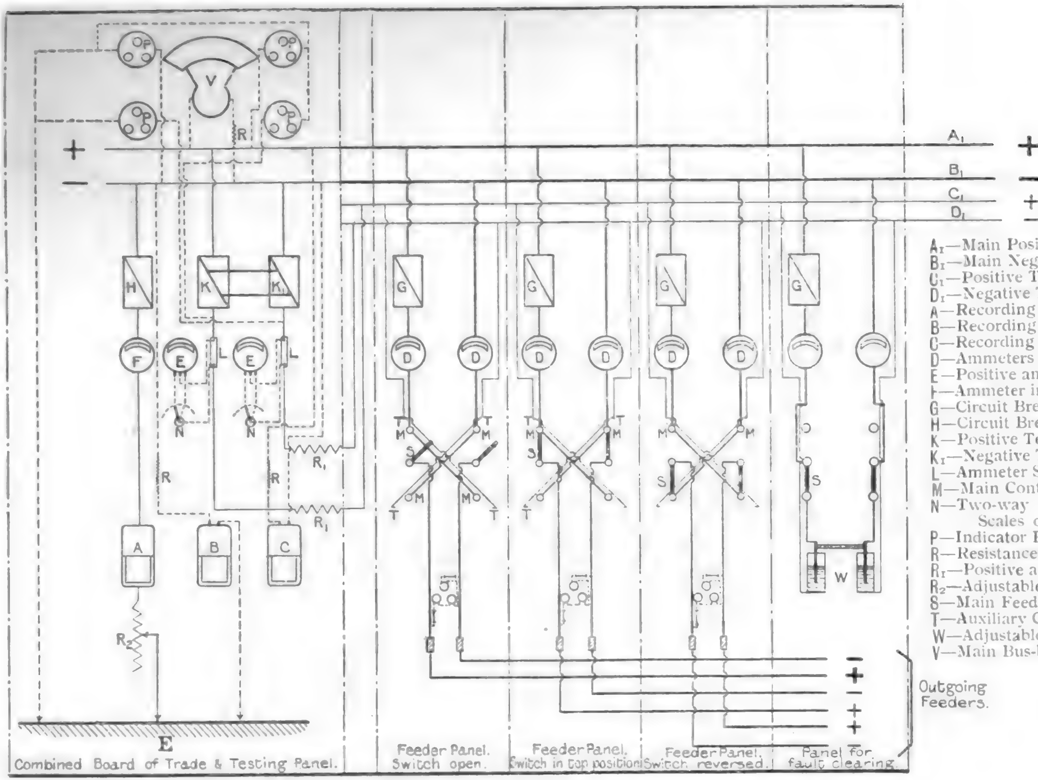
Clapham	9.	Brixton	9.	Elephant and Castle	18.
Streatham	7.	Camberwell	8.	New Cross	12

The feeder switchboards at Clapham, Brixton, and twelve of the feeder panels at the Elephant and Castle were supplied by Messrs. Cowan's, Ltd., of Salford. The feeder switchboards at Streatham, Camberwell, New Cross, and six of the feeder panels at the Elephant and Castle were supplied by Bertram Thomas, of Hulme, Manchester. The circuit breakers on the Cowan's switchboards are of the "I.T.E." carbon break type, and those on the Bertram Thomas switchboards are of the magnetic blowout type. The equipment of each feeder panel is as follows:—

1 circuit breaker set at 500 amperes.
2 ammeters reading to 500 amperes, one in series with the positive track feeder and one in series with the negative track feeder.
1 double pole reversing switch with auxiliary testing contacts.
1 pilot lamp connected across track feeders.

The B.O.T. and Testing Panel.—The usual recording meters and testing apparatus are fixed to this panel. The auxiliary contacts on the main switches can be connected to small positive and negative bus-bars at the back of the B.O.T. panel by closing two circuit breakers on this panel: ammeters and resistances are in series with these breakers. If the main switch be pulled forward on to the auxiliary contacts and the testing breakers closed, by the readings on the testing ammeters the state of the feeder, track, etc., under test can be ascertained.

Earthing of System.—A circuit breaker connecting the negative bus-bar to earth, through an adjustable water resistance, is fixed on each B.O.T. panel. As the negative bus-bar at Loughborough is common to the three low tension substations, the earth breaker is only closed at



A_1—Main Positive Bus-bar to carry 3,000 amperes.
B_1—Main Negative Bus-bar to carry 3,000 amperes.
C_1—Positive Testing Bus-bar.
D_1—Negative Testing Bus-bar.
A—Recording Ammeter in Earthing Circuit.
B—Recording Voltmeter between Negative and Earth.
C—Recording Voltmeter between Bus-bars.
D—Ammeters in Feeder Circuits.
E—Positive and Negative Testing Ammeters.
F—Ammeter in Earth Circuit.
G—Circuit Breakers in Earth Circuit set at 500 amperes.
H—Circuit Breaker in Earth Circuit set at 100 amperes.
K—Positive Testing Circuit Breaker.
K_1—Negative Testing Circuit Breaker.
L—Ammeter Shunts for Testing Ammeters.
M—Main Contacts of Feeder Switch.
N—Two-way Switch for High and Low Reading Scales of Testing Ammeters.
P—Indicator Pilot Lights.
R—Resistances in Series with Voltmeters.
R_1—Positive and Negative Testing Resistances.
R_2—Adjustable Resistance in Earthing Circuit.
S—Main Feeder Switch.
T—Auxiliary Contacts on Feeder Switches.
W—Adjustable Resistance in Fault Clearing Circuit.
V—Main Bus-bar Voltmeter.

L.C.C. TRAMWAYS.—Diagram of Connections. D.C. Feeder Switchboards.

Brixton. An ammeter, and a recording ammeter, both reading to 100 amperes, are in circuit with the earth breaker at all substations. If a positive earth occurs anywhere on the system fed from the three low tension substations, the current returns to the negative bus-bar at Loughborough through the earth breaker in the Brixton substation. Four pilot lights are fitted at the top of the B.O.T. panel. The two top lights are always alive, whilst the two bottom lights are only made alive when the testing breakers are closed. The right hand lights are connected between the positive bus-bar and earth, whilst the left hand lights are connected between the negative bus-bar and earth.

Effects of an Earth occurring on the System.—If a severe positive earth occurs on a car or on any track, the potential difference between the positive bus-bar and earth drops to zero. As the full potential difference of 550 volts is still maintained across the feeder bus-bars, the potential difference between the negative bus-bar and earth must immediately increase to 550 volts. The negative bus-bar is therefore at a potential of 550 volts below earth potential, as current is returning from earth to the negative bus-bar through the water resistance, etc. The drop in pressure of the negative bus-bar is entirely due to the leakage current returning to the negative bus-bar through the adjustable water resistance.. The water resistance under normal working conditions should have a resistance of about 18 ohms. Thus, with a leakage current of 30 amperes, the full potential difference of 550 volts will be dropped across the water resistance.

Effects of an Earth on the Pilot Lights.—When an earth occurs the pilot lamps between positive and earth go out, owing to there being no potential difference between positive and earth. The pilot lamps, connected between negative and earth light up, as the potential difference between negative and earth immediately increases to 550 volts. The section on which the fault has occurred is then located by observing on which feeder panel there is a difference of reading on the track feeder ammeters. If the fault is a serious one, the main feeder switch must be reversed, thus bringing the fault on the negative side of the system.

The leakage on one half-mile section of tramways is about 0·3 ampere at the line pressure. This is sometimes exceeded during wet weather, and is less during dry weather. This constitutes a loss of 3·96 B.O.T. units on each half-mile section for 24 hours, due to line leakage. As there are 54 — ½ mile sections supplied with electric current throughout the 24 hours, the total loss in B.O.T. units for the system daily $= 54 \times 3{\cdot}96 = 214$ B.O.T. units.

Total units consumed on the system for 24 hours

$$= 50{,}000 \text{ B.O.T. units.}$$

$\therefore$ loss due to line leakage

$$= \frac{214 \times 100}{50{,}000} = 0{\cdot}428 \text{ per cent. of total units generated.}$$

The plant owned by the London County Council at the London

Electric Supply Company's Generating Station at Deptford is three-phase, and consists of the following :—

Engines.—The London County Council have erected two 1,500 k.w. steam generators. The engines are in every respect similar to those at Loughborough Junction.

Generators.—The magnet wheels of the three-phase alternators are mounted on the shaft between the two cylinders of the engines. These alternators generate three-phase alternating current at a pressure of 6,600 volts between phases at a frequency of 25 cycles per second. The full load current of these generators is 133 amperes per phase, with a power factor of unity. There are 40 slots per phase, thus giving a total of 120 slots. The slots are fully open, and the former wound stator coils are kept in the slots by means of wooden wedges.

Exciter Plant.—The rotor of each alternator receives its excitation from a small rope-driven dynamo. These machines are of 30 k.w. capacity, and generate direct current at a pressure of 125 volts. The full load exciting current for one alternator is 120 amperes.

Switchboards.—The switchboards controlling the power generated by these alternators and exciters are situated on a gallery close to the main engines, and, together with the high-tension switchboards, direct-current exciter and generator switchboards at the New Cross, Camberwell, and Elephant and Castle substations, were supplied and erected by the British Westinghouse Electric and Manufacturing Company, Limited, of Manchester.

The switchboard at Deptford consists of a high-tension generator and feeder board and an exciter switchboard. The high-tension board consists of six white marble panels, which are bolted to angle irons. The angle irons are supported from the wall by horizontal circular rods. The high-tension bus-bars chambers are situated at the back of these panels. They consist of three brickwork chambers, one above the other, and separated from each other by 1½ in. slate partitions. The high-tension switches both at Deptford and in the converting substations are of the hand operated oil type, automatically released. Each generator and feeder panel is fitted with one of these oil circuit breakers, which is fixed to the back of the panel. There is a separate wood-lined oil tank for each phase, and the fixed contacts of the switch are enclosed and supported by porcelain insulators fixed into the top plate of the switch. The bottom part of these fixed contacts, which is under oil, is hollowed out to admit the contacts completing each phase circuit. The movable portion of the switch consists of a crosshead, which can be lifted up or down by a lever projecting through the front of the panel, in combination with suitable toggle jointing. Three stout wooden rods are suspended from this crosshead, and copper arms, with a cone contact at each end, are fixed to the bottom of the wooden rods. When the crosshead, and consequently the three copper bars, are lifted, the circuit is closed for all three phases.

The instruments fixed to the high-tension switchboard at Deptford consist of recording kilowatt meters, polyphase overload and reverse current relays, etc. The synchronising bars are fixed at the back of

the panels ; connections from the generators, before entering the high-tension oil switch, are made to the back of a three-pole plug-socket. If a three-pole synchronising plug is inserted into this socket from the front of the panel, the generator is put into connection with the synchronising gear. A feeder-charging panel is fixed at Deptford, and also at the converting substations. By closing a small oil switch fixed to this panel any desired feeder can be connected to the main bus-bars through a water resistance. The resistance can then be reduced until the feeder is fully charged. High-tension fuses and three ammeters are in series with this water resistance. The three feeder panels at Deptford control the outgoing feeders to the converting substations at New Cross, Elephant and Castle, and Camberwell. The feeders are of the 0·15 sq. in. 3-core paper-insulated and lead-covered type, with an earthing shield of copper between the lead and the paper. These feeders, and also the interconnecting cables between the substations, were supplied by Messrs. Siemens Bros., Limited, of Woolwich. Each panel has an oil circuit breaker, similar to the one described above, and suitable relays and recording instruments. At each end of the high-tension board two voltmeters reading to 9,000 volts, a synchroscope, and two synchronising lamps are supported on a swinging bracket. All pressure instruments, shunt coils of relays, wattmeters, etc., are worked off the secondary side of shunt transformers, the pressure of which is 110 volts. Series coils of relays, wattmeters, etc., are supplied from the secondary terminals of current transformers.

The exciter switchboard at Deptford consists of three white marble panels. Each rope-driven exciter panel contains suitable switches for exciting either rotor with exciting current from its own exciter, or with current from the exciter bus-bars to which the steam exciter set could be connected if necessary. Two ammeters are provided on each panel, one showing the rotor-exciting current, and the other showing the output of the rope-driven exciter. The third exciter switchboard panel is equipped as a generator panel for the 157½ k.w. steam exciter set.

The power generated at this station, amounting to 23,000 B.O.T. units in 24 hours, is consumed on the Peckham, Greenwich, Camberwell, Walworth Road, and Southwark Bridge routes.

Substations.—The substations at Camberwell, New Cross, Elephant and Castle, Clapham, and Brixton consist of a large machine-room with basement, battery-room, workshops, and engineers' mess-rooms.

The switchboard gallery in all substations is raised about one foot above the machine floor. The floors of the machine-rooms, switchboard galleries, and the bases of the machines are laid with terrazo paving. All cable connections between machines, rheostats, etc., and the switchboard are in the basement, and the incoming and outgoing feeder cables also enter and leave the substation through ducts which lead into the basement. In all substations a 10-ton overhead travelling hand crane is used for moving the machinery where required.

The substations at Camberwell, New Cross, and the Elephant and Castle have been equipped with 300 k.w. synchronous motor generators

with suitable controlling switchgear for converting the power received from Deptford into direct current for use on the tramways.

Induction motor generators of 500 k.w. capacity will shortly be installed at Streatham, Brixton, Greenwich substation, and Clapham in readiness for the Greenwich supply. The number of converting machines at present installed at the Elephant and Castle, New Cross, and Camberwell is 5, 4, and 3 respectively.

The motor generators are of exactly the same design and capacity. They were made by Messrs. Dick, Kerr & Co., Limited, of Preston. Each machine consists of an A.C. revolving field motor, a D.C. traction generator, and an 8-k.w. exciter. The bed-plates are hollow, and are bolted to the floor of the substation by six 2-in. bolts. The alternating current motor is of the revolving field type, with wholly laminated poles dovetailed into the spider, and the stator is wound for 6,600 volts. The cable, leading from the switchboard to the stator coils, terminates in a trifurcating box which is filled with insulating compound. The overall flow space occupied by one of the motor-generator sets is 162 sq. ft.

The following are some details of the converting sets :—

Motor.—Speed, 300 r.p.m. Frequency = 25 cycles per sec. B.H.P. = 450. Amperes per phase on full load assuming $\cos\phi = 1$, are 30 amps. Diameter of rotor = 5 ft. Outside diameter of stator, 8 ft. 2in. Peripheral speed of rotor in feet per minute = 4,712 ft./min. No. of poles, 10.

D.C. Generators.—K.w. = 300. Full load volts = 550. Full load amperes = 545. Diameter of armature = 3 ft. 6 in. Diameter of commutator = 2 ft. 6 in. No. of commutator strips = 336.

The machine switchboards in the three substations comprise high-tension feeder and motor panels, traction generator panels, and exciter switchboards. The high-tension switchboards are all equipped with hand operated oil circuit breakers, released automatically, and suitable registering instruments.

Arrangements of H.T. Switchboards etc., in Substations.—The panels are fixed three feet from the side wall of the station. The bus-bars are supported by insulators, fixed in separate bus-bar chambers, situated in the substation basement. All cables, connections, etc., from the bus-bars to the oil switches at the back of the panels pass through square holes in the gallery floor, of which there is one behind each panel. The shunt transformers for working the shunt coils of wattmeters, relays, etc., are situated in the basement, against the wall and opposite the bus-bar chambers. Each set of shunt transformers is entirely enclosed in a slate cubicle, which has a removable cover, and each cubicle is labelled with the name of the panel, to which the enclosed transformers belong. The space between the slate cubicles against the wall and the bus-bar chambers forms a convenient passage from which the whole of the high-tension gear in the basement can be inspected.

Interconnecting High Tension Feeders.—Each substation is fed with current through the Deptford Trunk Main for that substation, but if this feeder should fail, the station would be supplied through one or two

interconnecting cables from the high tension bus-bars of another substation. These interconnecting cables are three-core 0·075 sq. in., and are rated at 500 k.w. In order to assure that the cables are all in good working condition, the cables are worked on load several times each week.

Direct Current Machine Switchboards in Substations.—The panels controlling the 300 k.w. traction generators are fitted with circuit breakers and knife switches on both poles. The circuit breakers are of the Westinghouse carbon break type with a time limit for overload adjustable from 0–10 seconds. The time limit clockwork is started by the attraction of an armature when an overload occurs, and the tripping gear of the circuit breaker is also operated when the overload has lasted for the number of seconds for which the time limit is set. A station output panel is erected in all substations in connection with the D.C. machine switchboards. Two voltmeters are fixed on a swinging bracket supported from this panel, and a B.T.H. integrating wattmeter for a load of 3,000 amperes at 600 volts is also fixed to this panel.

The exciter switchboards in the substations are situated opposite the high-tension switchboards. These switchboards comprise machine panels for controlling the 125 volt exciters on the large motor-generator sets, and also station lighting panels. The arrangements of switches on the machine panels have had to be specially arranged in order to provide for the starting up of the large motor generator sets off the exciter, the exciter being used temporarily as a 125 volt motor, as well as to provide for the excitation of the rotor-field magnet, when the exciter is running as a generator.

When the substations are completely shut down, the machines are started up by the exciter. The source of supply of the 125 volt current is an induction motor generator of 50 k.w. wound for 6,600 volts on the motor and 125 volts on the generator. One of these induction motor generators together with its three-phase rotor starting resistance is installed in each substation. The starting resistances, shunt-field resistances, and rotor-field resistances are all fixed in the basement, being worked by hand wheels fixed to columns, which are in front of the respective panels. All starting- and field-regulating resistances were supplied and erected by Messrs. Cowan's, Ltd., of Salford, Manchester.

Equalising and Starting Arrangements.—A combined equalising and starting switch is fixed on the bedplate of each motor generator. There are three positions for this switch :—

(1) Starting position. For running up the machine, using the traction generator temporarily as a shunt motor.
(2) Running position. Generator running as a compound wound machine.
(3) Off position. Direct current generator disconnected from all circuits whatever.

The three-phase alternators at Deptford are shut down from 1.20 a.m. to 4.45 a.m., and consequently the substation machines are also shut

TATION.

SCHEDULE O EM OF TRACTION: UNDERGROUND CONDUIT WITH

Converting I Direct Current. 5 D.C. Tramway Track Feeders.

MONTH.	ES New Road.	REMARKS.
January, 1904 (8 days) ...		
February, 1904 ...		The 82 minutes' delay on Addington Square was caused by a fault on a plough.
March, 1904...		The 28 minutes' delay was caused by converting machines being shut down six times.
April, 1904 ...		No track faults. Delay caused by converting machines being shut down twice.
May, 1904 ...		No track faults. Delay caused by converting machines being shut down twice.
June, 1904 ...		No track faults. Delay caused by converting machines being shut down four times.
July, 1904 ...		One "short circuit" on Shenley Road lasted 3 minutes. Other delay caused by machines shutting down.
August, 1904		One "short circuit" on Shenley Road lasted 10 minutes. Other delay caused by machines shutting down.
September, 1904.	3	No track faults. Delay caused by converting machines being shut down.
October, 1904		One "short circuit" on Shenley Road lasted 14 minutes.
November, 1904	7	Fault on Camberwell New Road for 14 minutes. Other delay caused by machines shutting down.
December, 1904	5	No track faults. Current off tracks due to converting machines being shut down.
January, 1905 (23 days)	5	One "short circuit" on Camberwell New Road lasted for 13 minutes. Plant shut down once.
Totals ...	50	

; first 8 months.
n Substation for working all-night cars, etc.

short circuit, 27; overload, 105.

down. Arrangements have had to be made to supply the sections, supplied with current from the converting substations, with power from Loughborough during the night, as all-night cars are run on the Greenwich and Peckham routes. The effect of supplying the whole system from Loughborough is to improve the night-load factor at the latter station. All three substations are started up again by 5.30 a.m., and the load at Deptford at that hour is between 800 and 1,000 k.w.

Bankside Substation.—This substation is situated in the generating station of the City of London Electricity Supply Co. at Bankside, and was equipped for the purpose of assisting the Deptford plant at times of heaviest load.

The London County Council have erected four 300 k.w. motor generators exactly similar to the machines in the converting substations. Direct current is supplied by the Lighting Company at 430 volts, and this current is transformed into three-phase current at 6,600 volts. The alternating current is transmitted to the Elephant and Castle substation by means of 2–0·075 sq. in. 3-core cables during the times of heaviest load at Deptford; and this transforming plant works in parallel with Deptford at the Elephant substation. The direct current motor switchboards and the alternating current generator switchboards at Bankside were made by Messrs. Dick, Kerr & Co., Ltd.

The bus-bars are supported on insulators fixed to angle irons about two feet above the top of the board, and the switches, which are of the oil type, hand operated, are fixed to the wall behind the panels. The direct-current circuit breakers are of the metallic shield magnetic blowout type. No automatic relays are connected to the feeders at Bankside, but at the Elephant the Bankside feeders are connected up to the Westinghouse switchboard through the usual relays, circuit breakers, etc. The output in B.O.T. units to the Elephant and Castle from Bankside averages 5,000 per day.

Streatham Generating Station.—This station is situated at the Streatham depôt of the Council's tramways, and has been equipped with plant for the supply of power to the Streatham route of tramways. The main engines which were used for working the original cable line on Streatham Hill are now used for driving a 300 k.w. dynamo. There are two horizontal engines, each capable of giving 700–800 H.P., fixed side by side. Either of the two engines can be coupled up to a grooved pulley, 10 ft. diameter. This pulley is connected by 12 spliced ropes, 2¼ in. diameter, to a smaller pulley, 2 ft. 6 in. diameter, which is coupled to the armature of a 300 k.w. continuous-current dynamo. The distance between centres of two pulleys is 40 ft. The engines are compound, cranks at 90°. Diameter H.P. cylinder 20¼ in., diameter L.P. cylinder 30½ in. Stroke 50 in. R.p.m. = 78. Steam is supplied by five Babcock & Wilcox boilers at a pressure of 140 lbs./sq. in. The admission (high pressure steam) and governing gear is of the Proell type, all other valve gear is positive-driven Corliss. The switchboard at this station comprises seven feeder and one generator panel, and was made by Bertram Thomas, of Hulme, Manchester. It is exactly similar to the boards in the converting substations. During the first year of

running on the electric system, the plant ran for 6,698 hours, and during this time the dynamo generated 1,399,907 B.O.T. units.

Summary of Units Generated at all Stations for Twenty-four Hours.

Station.	Units Generated.	Load Factor.	Maximum Load.
Loughborough ...	25,000	per cent. 62	2,000 k.w.
Deptford	23,000	68	2,200 "
Streatham	5,000	70	550 "
Bankside	5,000	50	700 "

Total units generated for twenty-four hours = 58,000 B.O.T. units, or an average of 21,000,000 units per annum.

III. The Equipment of the Tramway Tracks including the Method of Supplying Tracks with Current.

The positive and negative conductor tees on the up and down tracks are connected by means of jumper cables to the feeder pillars, which are placed in a convenient position at the side of the road.

Feeder Pillars.—The pillars are placed at the ends of every half-mile section, and are designed to deal with the following requirements:—

(1) Supply of current to either of the two half-mile sections to the right and left of the feeder pillar.
(2) Supply of current, if necessary, to both half-mile sections to right and left of the feeder pillar.
(3) Provision for the disconnection of feeder cables from the feeder pillars, and the feeder pillars from the line.

The feeder pillars are provided with a door at the back and front, and both these doors open on to a small track switchboard fixed to the sides of the box. There are eight switches on the front of this panel, the four top switches being positive, and the four bottom switches negative. Any set of two switches, one above the other, controls the positive and negative tees for one track to the right or left of the box. By rearranging the linkwork at the back of the switch panel, any of the requirements enumerated above can be effected. The switches in the feeder pillars are of the quick break type, and are capable of breaking a current of 300 amperes at the line pressure. In all feeder pillars a telephone is fixed communicating with the nearest sub or generating station.

Connections of Conductor Tees at Points, Cross-overs, etc.—The conductor tees are necessarily cut at points in order to allow ploughs on cars to take any road. The length of the gap in the tees at a right angle cross-over is about 2 ft., whilst at a turnout or cross-over from

one road to another it is about 12 ft. The tees are connected together at such places by 0·25 sq. in. vulcanised bitumen cables, which are laid in ducts at the side of the tracks. For a simple cross-over from one track to another, two ducts, one each by the side of the up and down tracks, are required; one duct for the cable connecting the break in the positive tee on one track, and one duct for the cable connecting the break in the negative tee on the other track. Only one conductor tee in each conduit is cut in the case of a simple cross-over, the conductor tee on the outside of each track being continued right along.

IV. Rolling Stock, Car Sheds, etc.

Four hundred electric cars have been supplied to the London County Council Tramways, and approximately 370 of these cars are running on the routes during the heavy hours in the morning and evening. Two hundred of these cars are single-truck cars, and two hundred are maximum traction bogie-truck cars. One hundred cars of each type were supplied by Messrs. Dick, Kerr & Co., Ltd., of Preston, whilst one hundred of each type were supplied by The British Westinghouse Electric and Manufacturing Co., Ltd., of Manchester. All cars have been designed for working on the conduit system. This necessitates fitting the cars with a plough carrier and plough instead of the trolley standard and trolley boom used on the overhead system; it also necessitates the insulation of the negative leads on the cars being as good as the insulation of the positive leads, as at any time the car may go on to a section with the polarity of the conductor tees reversed with respect to the last section. The leads, which were negative, are then positive, consequently the insulation of both poles must be equally good.

Car Bodies.—The total length of a bogie-truck car is 32 ft.; and the length of a single-truck car is 27 ft. 3 in. The width of the cars is 6 ft. 8 in. The seating capacity of the bogie-truck cars is 66 passengers; that of the single-truck cars, 56 passengers; the length of the minimum seating allowance being 1 ft. 5 in. inside the cars, and 1 ft. 4 in. outside the cars.

Motors.—The electrical equipment of the cars supplied by the two firms does not differ except in small details. Two series-wound motors are fixed on all cars; the single-truck cars having two 25-H.P. motors; and the bogie-truck cars two 37-H.P. motors.

Controllers.—The controllers of the cars supplied by Messrs. Dick, Kerr & Co. are fitted with their metallic shield solenoid blowout. This solenoid extends the whole length of the controller. Copper rings are placed round the windings of the solenoid, one ring for each contact finger on the central barrel of the controller. The various rings are divided from each other by ebonite division pieces. When in working order this solenoid is placed close to the point, where the movable fingers on the central barrel break contact with the fixed fingers. The effect of the solenoid is to draw the arc, produced by breaking the current, round the copper shield where it is finally ruptured.

The controllers on the Westinghouse cars are of the standard Westinghouse design. The current is broken at nine contacts in series. This has the effect of breaking $\frac{1}{9}$th of the total motor current at each contact.

Brakes.—All cars are fitted with two kinds of brakes :—

(1) Hand brakes.

(2) Electric rheostatic brakes.

The hand brakes are of the ordinary type; the retardation of the car being effected by the pressure of brake blocks on the wheels.

The electric rheostatic brakes are only used in case of emergency. The braking is effected by short circuiting the motors gradually through a resistance; as the motors are being driven by the car as generators the retardation is practically proportional to the speed of the car.

Sanding Gear.—The cars are fitted with "intermittent action" sanding gear. This is operated by a foot pedal from either end of the car. The valves in the sand boxes, which are placed underneath the car seats, open at each movement of the pedals.

Plough Carriers.—The plough carriers on the single-truck cars consist of two special angle irons fixed at right angles to the side frames of the car truck. The plough, which is free to slide on the angle irons laterally, is prevented from rising too much when the car is moving, by two smaller check angle irons, which are fixed to the plough carrier, above the top of the plough shank.

The plough carriers on the bogie-truck cars are similar in general design to those used on the single-truck cars, except that the framework is stronger, as the plough carrier is only supported at one side by an extension of the bogie-truck framework beyond the pony wheels of the bogie truck.

Ploughs.—The plough is probably the most important piece of apparatus in connection with the conduit system. It is the device by which the current is conducted from the underground conductor tees, through the slot in the road, to the terminals of the car controller.

It is a difficult matter to bring two insulated conductors, with a potential difference of 550 volts between them, through a slot $\frac{3}{4}$ in. wide, and at the same time make a fairly strong mechanical job. It must be understood that during wet weather the movement of the car wheels sprays the water from the running rails on to the plough shanks, whence it runs down on to the plough shoes and fuses; and also that after heavy rainfall the contact shoes and flexible fuses on the ploughs have water dripping on to them through the slot in the road the whole time the ploughs are in use. The ploughs at first used on the London County Council lines were similar in construction to those in use at New York, Paris, etc. The part of the plough passing through the slot consists of two steel plates, about a foot wide, screwed together. Between these plates the positive and negative steel conductors ($1\frac{1}{8}$ in. $\times \frac{1}{16}$ in.) are placed in suitable slots cut in the steel plates. The strips serve to connect the plough shoes, fixed on to the bottom part of the ploughs, and which are in constant sliding contact with the conductor

tees, to the plough leads at the top of the plough. The plough shoes are 6 in. long and 3 in. wide and are made of cast iron. They are supported from the bottom of the plough by a steel link which is fixed to the shoe, but is hinged at the point where it is supported by the body of the plough. A flat steel spring also presses up against the inner side of the shoe, the ends of the spring sliding in suitable guides in the shoe, and on the body of the plough.

Insulation of Conducting Strips from Side Plates of Ploughs.—The insulation used at first was a few layers of black insulating tape round the strip. During wet weather the water permeated through the body of the plough, which was made of wood. The black tape soon became damp, and the positive lead earthed on to the side plate of the plough; this caused a dead positive earth. Trouble was also caused by water dripping through the slot in the road on to the plough fuses. These fuses, which are made of copper gauze, $\frac{1}{8}$ in. diameter, serve to make the flexible connection between the plough shoes and the conducting strip terminals at the bottom of the plough body. This trouble was obviated by fixing an indiarubber hood about 2 in. wide all round the shank of the plough, just covering the fuses and contact shoes. In wet weather this has the effect of keeping the bottom part of the plough fairly dry.

The plough fuses are only supposed to blow in case of a dead short circuit in the plough itself; experiments have determined that the fusing current for these copper gauze fuses is about 500 amperes. It thus became necessary to insulate the conducting strips in the ploughs with something better than black insulating tape, and also to make the body of the ploughs with something less impervious to moisture than hard wood. The strips on all ploughs used at present are enclosed and insulated by pure rubber sleeves $\frac{3}{32}$ in. thick; this has proved to be a great success. As rapidly as possible all wooden ploughs are being taken out of service, and ploughs with the bodies made of vulcanised indiarubber are being substituted in their place. These ploughs are wholly rubber, except the heads, the steel side plates and contact shoes.

It is necessary to dip the wooden ploughs in a bath of insulating compound every night; the plough must then be dried in a properly-equipped drying chamber. This dipping and drying will be obviated when the new type of plough is in use on the whole system.

Car-sheds.—There are three car-sheds at present in use for housing the cars at night.

The numbers of cars stationed at night (February, 1905) in the various sheds is as follows :—

Clapham car-shed ...	...	164 cars.
Rye Lane shed ...	...	117 cars.
New Cross shed ...	...	85 cars.

The Clapham car-shed, which is situated in Clapham High Street, has been entirely rebuilt and adapted for housing cars on the conduit system. It is capable of accommodating 164 cars. The New Cross

car-shed has only been recently completed, and is capable of accommodating 290 cars. The Rye Lane car-shed is an old horse-car shed. It has been adapted for housing electric cars temporarily whilst the new sheds are being completed. The overhead system is in use in the Rye Lane car-shed. As each car reaches this shed, the plough is removed, and flexible leads from an overhead trolley are connected on to the controller leads of the car; the latter can then be moved to any part of the shed. The new car-sheds at Camberwell and Streatham are in an advanced stage of construction.

Clapham Car-shed (*Standard Conduit System Car-shed*).—This shed was rebuilt on the site of the old horse sheds at the beginning of 1904. The complete shed consists of six bays, each bay being about 50 ft. wide. There are 28 tracks, and the car-traverser pit runs the whole width of the 28 tracks. Two traversers are used during the times when great numbers of cars are run in or out of the shed. The conduit in this shed is built up of wood, and is deflected to the side of the tracks, so that the whole of the pits are clear for the inspection of car motors, etc. The wood for forming the conduit is supported at each pier by a small girder which projects from the pier; the conductor tee nearest the pier is supported by specially-designed insulators, fixed to the small girder, and is usually made the positive tee. The other conductor, which consists of a piece of strip steel, is screwed to the vertical piece of wood forming the front side of the conduit. By diverting the car-shed conduits to the side of the pits, it is possible to have the whole pits clear for inspection, and yet be able to move the cars anywhere up and down the tracks with their own plough. The side slot in the car-sheds is about 3 in. wide.

For the supply of current to the car-shed tracks, a track switchboard is fixed in the shed. This switchboard is fed by a positive and negative feeder from the nearest substation. There is a positive and negative switch controlling each track, and 0·25 sq. in. vulcanised bitumen cables run through ducts from these switches to the conductor tees on the various tracks.

Special car repairing, plough repairing, fitting and paint shops, are in full working order at this depôt. The various machines in the workshops are driven by a 14-H.P. 550-volt shunt motor. The leads for this motor are connected on to the substation bus-bars. The Clapham and New Cross sheds are lighted by arc lamps at night, 40 being used in the former shed and 70 in the latter.

In conclusion, the author hopes that the description of the power plant, system, etc., of the London County Council Tramways will prove of interest to the Institution, and he wishes to express his thanks to Mr. A. L. C. Fell, Chief Officer, L.C.C. Tramways, and to Mr. J. H. Rider, Chief Electrical Engineer, L.C.C. Tramways, for permission to read the paper. The latter also kindly corrected the paper and lent various apparatus and drawings. The author is also indebted to Mr. Bertram Thomas for the loan of a standard-traction circuit breaker, and to the *Electrical Review* and various contracting firms for permission to reproduce certain photographs as lantern slides.

BIRMINGHAM LOCAL SECTION.

APPLICATION OF ELECTRICITY TO MINES.

By A. C. ANDERSON, Student.

(*Paper read before the Section on Feb.* 15, 1905.)

There is no longer any need to discuss the advisability of using electric energy for light and power in mining work. There is scarcely a technical paper nowadays which does not contain a note to the effect that electricity is to be installed in some mine or that such an installation has established its superiority over other systems of driving. Steam is impossible owing to the prodigious condensation losses in lines of piping. Mr. W. C. Mountain* has said that "Careful tests were made to demonstrate what was the condensation in the steam pipes in a pit shaft, and it was found that with well-covered pipes the condensation was approximately one-third of a pound per square foot of exposed surface, based on the outside diameter of the pipe itself. For instance, a 6-inch pipe with an outside circumference of about two feet, would condense about two-thirds of a pound of steam per hour per foot of length."

Compressed air, electricity's only formidable rival for power, is still finding favour in some places for coal-cutting machinery, but even then the compressors are electrically driven, the compressed-air gear being purely subsidiary to, and a part of, the electric installation. Extensions are very easy on this system, as the compressors may be readily moved forward. At the Wharncliffe Silkstone Colliery, which has upwards of 800 H.P. in compressed-air plant installed, a change is being made in favour of electrical driving, as the efficiency of the present system is only about 30 per cent. In the case of the St. John's Colliery, Normanton, Yorks., also, electricity has proved more economical and convenient than compressed air. It has been argued that the exhaust from pneumatic motors has a beneficial cooling effect, but the proportion of the exhaust air to the main current flowing is so small as to hardly affect the temperature. The South Staffordshire Mines Drainage Commission, which commenced nearly two years ago to drive its surface pumps electrically, has found the results very satisfactory. It has reported that there has been less time spent in pumping, and that a further decrease is expected as steam is replaced more fully by electricity. Mr. Henry Hall (H.M. Inspector of Mines for the

* *Electrical Review*, vol. 48, p. 238, 1901.

Liverpool and North Wales district), in a report on mines and quarries issued by the Home Office, states that no accidents during 1903 were attributed to electricity, while rapid progress was made in its application to pumping, coal-cutting, and hauling. It would be an excellent thing if the use of horses below ground could be entirely eliminated; they are most undesirable from the hygienic standpoint. Much has been done, both in the conversion of existing plants to electric driving and in the laying down of new installations. Satisfaction has been practically universal, and there can be no doubt that a great field has been opened for the enterprise of makers of electrical machinery for use in mines. In special circumstances, such as these, it must always be borne in mind that electricity is a "risk," like any other form of energy, and must be treated with due care. "Good work" should be the motto of an electric mining installation. The man who sacrifices efficiency and reliability to cheapness is courting disappointment and possible disaster. But given a sound, efficient system, carefully installed and properly handled, there cannot fail to be an appreciation of the advantages appertaining to electric transmission. Frequent reference is made below to the rules formulated by the Home Office Committee of Inquiry on the Use of Electricity in Mines, and throughout they are mentioned shortly as the "New Rules."

Choice of a System.

The mine-owner or manager who wishes to install electrical plant is immediately confronted with the question as to system. He wants the utmost efficiency and reliability, and these with a low capital expenditure and small maintenance costs. He will probably have received a large amount of contradictory advice as to the respective merits of direct-current and 3-phase alternating, and it is to be feared that the progress of electricity in mines is somewhat hampered by the inability of the non-electrical man to decide for himself on the best system for his special conditions.

It is urged that by the use of induction motors sparking is entirely obviated, a point of paramount importance in fiery mines. Certainly the possible sparking at the commutator of the D.C. motor is got rid of, but there always remains the chance of a break in the mains or failure of the windings.

Variable speed with alternating motors is a most difficult problem, and proscribes their use to a large extent. It is an absolute necessity with fans, as the air supply must be capable of nice regulation. Moreover, the choice of speeds is rather restricted with 3-phase motors. Alternating motors are very good when they can be run on constant load at constant speed, conditions met with in certain classes of pumping work, etc. By-passes can easily be arranged on the pumps to allow of gradual starting. Continuous current is eminently suitable for large machines, such as winding and haulage gears, and large pumps, owing to great comparative ease of starting and regulating.

Speed variation is practically essential in most of the departments

of mining work, and can now be accomplished very economically with D.C. machinery. In addition, a continuous-current system gives far better results on varying load (also an essential of mining work) than an alternating one. Mr. H. M. Hobart says that a C.C. motor for coal-cutting would for a given output and speed have a smaller diameter, a much deeper air-gap, a higher efficiency, and a lower temperature rise than a polyphase motor for the same work. Further, the regulation would be much more suitable for lighting circuits.

The E.M.F. of an alternating system is much more flexible than that of a direct-current one ; it is so easy to step up or down with static transformers, but it must be remembered that the frequency suitable for power is not suitable for lighting, a very important consideration, and one which by the introduction of further complication is likely to neutralise largely the copper economy incidental to the use of alternating currents. A D.C. plant for 500 volts, in the case of comparatively small plants, on the concentric system with earthed return is very good and elastic for all classes of work, but the choice of a system must really rest on the special circumstances of the particular case.

Generating Plant.

Without question all generators should be liberally rated. Machines intended for use below ground, including rotary transformers or motor generators, have to be specially designed for ease of transport. They should be as absolutely reliable as possible, both electrically and mechanically, and should be subjected constantly to the most thorough supervision. The New Rules have specially provided for the proper installation and care of the generating plant. It is to be hoped that there will no longer be any of that cramped huddling together of machinery, which, unfortunately, so often characterises mining installations.

Distribution.

The distribution system, comprising wiring and switch-gear, is from every point of view by far the most important factor in an electrical mining installation. The few isolated cases in which mining managers have actually condemned electricity as unsuitable have been almost entirely created by shoddy workmanship and thoughtless design in the wiring scheme. It is absolutely essential for the successful adaptation of electricity to mining, that the system of wiring, with its controlling gear, should be as "solidly" installed as possible with the greatest care and the best material, due regard being paid in the design to any special circumstances. All metallic sheathings, armourings and boxes should unquestionably be properly connected with earth. In an alternating system care must be exercised in the use of metallic armourings or the laying of cables in iron pipes, to minimise, as far as possible, inductive effects. Three-core cables should be used, not triple concentric, and the algebraic sum of the currents must equal zero, as otherwise the inductive effects of the three cores will be

unequal, and there will be a loss in efficiency. Moreover, in special cases, where for some reason D.C. and alternating mains have been laid in the same pit, great care must be taken to avoid the mutual effects of self-induction.

The most favourable means of laying cables varies largely with circumstances.

Bitumen-filled troughs are very good, but can very rarely be used in mining work without an additional armouring of the cables. Insulation, consisting of paper or jute sheathed with vulcanised fibre or vulcanised bitumen with a double armouring of galvanised steel wires, is very good for difficult situations. Opinions, however, vary widely as to the protective covering to be adopted. Trailing cables for use with coal-cutters and portable drills present a very difficult problem. It is a hard matter to combine proper flexibility with sufficiently strong and reliable armouring. Some engineers use oak or teak casing in taking the mains down the shaft, others clamp with massive wooden cleats. On the other hand, loose suspensions are often preferred as giving the cable a better chance of withstanding mechanical shock. It is a moot point as to whether roof suspension is better than an arrangement on the sides or in the floor. It really depends on the relative strength and general suitability of these three alternatives. Certain it is that unless proper means are taken to prevent it, a fall of roof will probably break the cable suspended therefrom—a very dangerous possibility in a "gassy" mine. With a roof-suspension some arrangement should be made such as that adopted at the Hulton Collieries, Bolton, where the cables are loosely suspended from the roof by means of spun yarn, so that in the event of a fall no undue tension is put on another part. It should not be possible for any circuit to be opened in the presence of an inflammable gas. Switches are better immersed in oil. With regard to the general control of the scheme, it is best to arrange a disconnection box to ground cables at the top of the shaft and a distribution board with switches and fuses immediately at the bottom. Switchboards of the skeleton type, where there is really no "board" at all, are excellent for straightforward work, as every detail can be so readily inspected. Mr. Roslyn Holiday, of the Ackton Hall Colliery, makes his own switchboxes for attaching to coal-cutter motors. They are fitted with an accurately machined cover and a cement joint. The switch-handle works into a box through a gland. The voltage is 320, and there has been no sparking trouble. The more complex forms of gear, especially motor-starting rheostats, should be designed for the utmost reliability and ease of working. The movement of the switch-arm over the contacts should be restrained in order to reduce the risk of an armature burn-out, an accident which should be rendered still more improbable by the use of proper protective devices in circuit with the machine.

Motors.

When inquiring for motors for use in mines, managers should invariably specify as clearly as possible the nature of the load, the

temperature, and any peculiar conditions under which the machine may have to work. The question of temperature is a difficult one owing to the very different conditions prevailing in different parts of the same mine; but the engineer should know where his motors are going, and can specify accordingly. Of course, in the case of portable gear, which may be used anywhere, the worst possible case must be provided for, and an adequate factor of safety allowed.

Totally enclosed motors for certain conditions are absolutely necessary, and unfortunately there seems some foundation for the assertion that anything quite enclosed is liable to neglect. They should be most carefully designed not to overheat, and should be rated carefully in accordance with the nature of the load, a special margin being allowed for coal-cutters and drills, which meet with the roughest treatment. The machine is not always switched off at once when the cutter jambs.

Mr. Garforth, of Normanton, who has made some very interesting experiments on the risks of explosion with motors, found that gas can get through an armature shaft-bearing, but not in sufficient quantity to cause an explosion internally. He also found that the internal explosion incidental to the admission of gas to the interior of a gastight case did not fire the gas outside the case. Mr. W. C. Mountain made some experiments with motors at the request of the Committee dealing with the use of electricity in mines. He got no explosion with a mixture of gas and air when the proportion of the former to the latter was as 1 is to 15. He was further able to increase this to 1 to 10, and even to 1 to 8, without the occurrence of any explosion. When he adjusted the brushes, with the set purpose of making the machine spark, an explosion took place when the proportion of gas to air was 1 to 10.

Applications.

(*a*) *Pumping.*—Electricity is most commonly applied in mines to pumping, a use to which it is eminently suited, especially in connection with centrifugal pumps at constant load. In the Monterrad pits of the Roche-la-Moliers and Firminy Mining Company, the workings being gassy, the motor (3-phase) has a closed circuit winding without slip-rings, and no switches are placed underground. To start the plant the generator, an inductor alternator, is fully excited, and then run up slowly, taking the pump gradually to full speed with it. Near Dortmund there are some 665-H.P. pumping sets taking current at 2,500 volts, where two methods of starting up are provided. The motor may be connected to the one of the two dynamos which is at rest and attain full speed with it. This is the simplest way. No collector rings are required on the motor, but it is first necessary to stop a dynamo. Two separate 3-phase circuits must be allowed for at the switchboard—one for ordinary light and power, and one for pump motors. It was found desirable to be able to start the motor direct, and an oil-cooled starting-box was put in, by which means resistance was introduced into the rotor circuit.

At Horcajo, in connection with electrically driven pumps, Heerwagen's short-circuited rotor answers very well. The stator bears nine coils, each of forty-two turns; the three coils of each phase are in series, but the 3-phases are connected in mesh fashion. The rotor carries 360 flat copper rods, arranged in two layers, in 180 holes, and is so connected that six rods are in series, thus giving sixty circuits. The centrifugal pumps can start with zero torque, gradually increasing, and can be brought to full speed when full of water in 100 seconds. The motors are started by means of an auto-transformer giving 400 volts, the primary pressure being 1,000 volts. When the auto-transformer is switched in the first motor is joined to the starting-bars, and takes at first from 200 to 240 amperes, but rapidly reaches synchronism. This point is marked by a sudden decrease in current strength, when the connections are changed over to the main bus-bars; so that the motor continues to run at full pressure. The second motor is then started in the same way, and the auto-starter finally cut out.

(*b*) *Winding and Haulage.*—Electricity has not as yet come much into vogue for winding in this country, though electrically driven haulage gears have made much headway. Of the many ingenious devices designed to meet the difficult conditions of a winding plant, the Ilgner Siemens and Halske is the best known. Here a multiphase current drives a motor direct coupled to the armature of a C.C. dynamo, the connecting shaft carrying a heavy flywheel. The direct current from the dynamo drives the motor coupled direct to the winding-drum. The energy thus stored in the flywheel is available for starting the cage, Speed variation is possible by varying the field strength of the dynamos (which should be separately excited) driving the winding-motor. Under ordinary working conditions an efficiency of 60 per cent. may be looked for. This figure represents the ratio of the power available for raising the load in the shaft to that at the terminals of the motor-generator. For winding, where electric driving has superseded steam, the cost of working has been much reduced, the steam consumption per H.P.-hour coming down to 24 to 26 lbs. on mineral raised. The constant turning moment of the electrical motor is more favourable to the life of ropes than the varying torque of steam engines. "Dancing" of the rope is done away with, and drums can be much lighter than with steam-winding plant. The Koepe pulley system of winding is specially suitable for electricity owing to the high speed. In an interesting paper on "Some Applications of Electricity in German Mines" (see *Electrician*, Jan. 27, 1905), the vital point of this system is described. There was exhibited at Düsseldorf a winding engine where the varying load was taken up by a storage battery, and to this an Ilgner drive has now been added. About 1,000 tons are raised per day. The Ilgner drive consists of a 300-H.P. motor on a 500-volt direct-current circuit driving a steel flywheel 4 m. diameter, weight about 40 tons, and a direct-current dynamo at speeds up to 350 r.p.m. The motor, flywheel, and dynamo are all arranged on the same shaft. The dynamo sends current up to 2,000 amperes into winding motors, whose terminal voltage increases to 500 volts. The balancing of power is

effected by the variation in speed of the flywheel shaft. The plant at the Thiederhall pit, installed by Siemens and Halske, is driven by two C.C. motors with an equalising battery for starting and speed regulation.

(c) *Coal-cutters.*—Coal-cutters should be lavishly designed for strength and reliability in working. They should be able to stand at least 30 per cent. overload for short periods and they must be reversible.

Provision must be made for carrying 70 yards or so of armoured cable on the motor truck, preferably coiled on a drum, and cable should be paid out as the cutter advances, a sufficient length having been provided for the face of coal to be cut during a given shift. Messrs. Ernest Scott and Mountain have been good enough to give me some details of a performance of one of their disc-type machines at the Smithywood Colliery, near Sheffield. These are set out in the accompanying table.

(d) *Drilling.*—With regard to rock drills, it is to be noted that :—

(1) With pneumatic drills there is the deafening noise of the exhaust, no power to draw back the drill when jammed in the bore-hole, and there are heavy losses in cumbersome piping. Moreover, a severe capital outlay is unavoidable owing to the large power and space required, and the plant when installed is very inefficient.

(2) Electric drills are much lighter and more handy than the

DISC MACHINE.

Working of Coal-cutter at Smithywood Colliery.

Date.	Time Started.	Time Finished.	Min. Run.	Depth of Undercut.	Thickness of Cut.	Material Cutting.
	P.M.	P.M.		ft. in.	in.	
Dec. 16	10.30	10.33	3	4 6	5	Stones, Coal mixed with Stone.
	10.34	11.34	60			
	11.46	12.50	64			
	1.16	1.33	17			
	2.20	2.23	3			
	2.29	2.31	2			
	2.33	3.0	27			
	3.7	3.33	26			
	3.36	3.39	3			
	3.50	4.2	12			
	4.26	4.56	30			
	5.9	5.20	11			
	5.21	5.33	12			
			270 min.	105 yds. cut.		

Total hours from first switch on to last, 7 hours 3 minutes.

$4\frac{1}{2}$ hours actual cutting.

2 hours 33 minutes changing cutter twice, running rope out 3 times.

Average amperes, 37. Average volts, 470.

above, occupying but little room. They are 30 per cent. cheaper in first cost than air drills, and the medium for transmission of energy is far more flexible and efficient. The Durkee electric drill is driven through a flexible shaft by an independent motor of 1½ H.P. The motion is given by a special crank, which gives a slow return and a quick forward or cutter stroke; the driving collar moves the drill spindle through springs so as to cushion the motor of the drill if the cutter is not striking the rock, and to allow for irregularities in the feed. The drill is rotated by the usual rifled rod and pawl. The machine weighs 230 lbs. without tripod, and makes 580 strokes per minute.

The Marvin percussion drill of solenoid type, requiring a special alternator, needs from 20 to 32 k.w. at generator, and delivers 450 to 550 blows per minute. In the mines of the Consolidated Cariboo Hydraulic Co., at Bullian, British Columbia, electric drills driven by D.C. portable 1½ and 2 H.P. motors are used. Three drills are said to have averaged 312 feet of holes in 10 hours through solid rock. Cost of current was 9·37 shillings, and lubricants, 7½d.; a blacksmith at 16·64 shillings, and a helper at 8·32 shillings must be added. The total cost of running the drills for 10 hours was about 131 shillings, saving approximately 208 shillings on hand-drillng. The power was generated by steam engines, so that the results cannot indicate the maximum efficiency obtainable. The consumption of power was considered without reference to wages. The tests were extensive enough to give good average values. An 86-in. hole, 2 in. diameter, was drilled in 19·08 minutes. The total consumption of power was 940 watt-hours, or 131 per foot. The cost was 5d. per k.w. hour which, at the rate of 131 watt-hours per foot drilled, is equal to 0·655d. per foot. The minimum cost of drilling with steam or compressed air is equal to 5d. per foot.

(*e*) *Ventilation.*—There are not many instances as yet in this country of electrically driven fans in mines, but at the Pelton Colliery, Durham, such a fan has replaced two steam-driven Guibal fans.

(*f*) *Locomotives.*—Pneumatic locomotives are very clumsy affairs when compared with the excellent electric types turned out by Messrs. Thomas Parker, Ltd., and others. Their excess in bulk and weight is largely due to the big cylinders of compressed air which they must necessarily carry. In consequence they are not so suitable as electric locomotives for low seams, save where considerations of firedamp make their use the more safe. There must be sparking at wheels of compressed air locomotives when skidding at starting or on gradients. It has been proved in South Wales that these sparks will ignite gas.

In conclusion, the author acknowledges his indebtedness to the evidence given before the Committee on the Use of Electricity in Mines in the preparation of the paper. All interested should study both it and the Committee's Report.

ELECTRIC HEATING: ITS HISTORY AND DEVELOPMENT.

By A. E. JEPSON, Student.

(*Abstract of Paper read before the Manchester Students' Section, Jan.* 13, 1905.)

The use of electricity for producing heat, and the application thereof, is by no means the novelty that it is popularly supposed to be. As early as 1815 there was an account published in the *Philosophical Magazine* of a paper contributed by Pepys, in which he related some experiments conducted by him with electrically-produced heat. He made a saw-cut in a piece of iron wire, into which he placed some diamond powder, and then covered the whole with an insulating powder, in order to confine the heat as much as possible. After subjecting the wire for a period of six minutes to a current sufficiently strong to raise it to a bright red-heat he allowed it to cool, and found that the wire adjacent to the saw-cut was converted into steel.

In 1827 Sir Wm. Harris gave an account of some experiments conducted by him on the heating of air in closed vessels by platinum wires. It was not, however, until 1841 that Joule discovered the law known by his name.

One of the first applications of this heating effect to commercial uses was made by Napier in 1844, when he patented an appliance for reducing metals.

Depretz, in 1849, described a small apparatus which consisted of a tube of sugar charcoal with a core ¼ inch in diameter, the total length being about 1 inch. The two ends were plugged with pieces of the same material, and a heavy current passed through, which brought the whole to a white heat.

As early as 1862 Monckton patented a furnace for reducing carbon and alumina, but owing to the scarcity of power and its excessive price at the time it was not a commercial success.

Again in 1880 Borchers succeeded in reducing oxides which up till that time were believed to be irreducible, but the method was not greatly improved upon for some time, chiefly owing to the high price of current.

In Hospitalier's "Domestic Electricity," published in 1885, accounts and illustrations are given of various oil and spirit lamps which were ignited by bringing a red-hot platinum wire over the wick, current being supplied from primary batteries.

The year 1887 saw the patenting and application of the Héroult process of obtaining aluminium from alumina, using cryolite as a flux,

and in 1894 the carbide industry came to be worked on a commercial scale, although the product had been known to chemists since the middle of the nineteenth century.

The manufacture of heating appliances of a substantial character for domestic purposes was begun by the Carpenter Electric Heating Corporation sixteen or seventeen years ago. Previous to this other firms had been at work, but some of the early articles were so unreliable that it is not surprising that the public were for many years altogether prejudiced against the use of electric heating apparatus. At about the same time that the Carpenter Electric Heating Corporation began to manufacture articles suitable for domestic and general use many other firms also took up the manufacture, but these, for the most part, had a very short life.

Within the last twelve years, however, great improvements have been made, though even now the commercial articles are far from standardisation. In some instances, 98 per cent. of the energy expended is usefully applied, and the only direction in which further improvement is possible is in the speed of operation and in adaptability, but there are many operations, such as cooking, which cannot be performed in less time.

It is obvious that no one heating element or unit is universally applicable to all operations. The following important qualifications are, however, necessary in all cases: First, the operation must be performed as quickly as possible, the speed being governed by the nature of it. Secondly, at the highest efficiency, and therefore at lowest cost. Thirdly, that there shall be no smell or dirt. As regards the first, the time limit is fixed not only by the nature of the operation, but by the fact that if heat is produced more quickly than it can be carried away by conduction, convection, and radiation, the temperature of the heater would become so excessive that the resistance would fuse. The second condition naturally varies with the nature and time of the operation, the higher efficiencies of 80 to 98 per cent. generally being due to the fact that the appliances have self-contained heaters, the lower efficiencies of 50 per cent. or under being obtained when the heat has to be transmitted between two more or less uneven surfaces, such as a pan of water on a hot-plate. The third is rather an important consideration, since, in these days of improved sanitary and hygienic conditions, any cooking or similar process that is only possible with an accompaniment of dirt and evil smells is, in the estimation of its users, on a level of one in which coal, coke, or gas is used.

One of the chief arguments against the use of electricity for heating purposes is its great cost, and one is constantly being reminded, when discussing the subject, of the price of current and the amount required for the various operations. There is no doubt that at present the price is rather high for general household use, but if electric power was used universally for heating purposes the load factors of the supply stations would materially increase, for the reason that the times at which meals are cooked occur, during the greater part of the year, on either side of the peak load. If we allow, then, that the apparatus have reached their

highest efficiency, it is clear that the first cost of apparatus and the price of current must be greatly reduced before their adoption for general use can be increased. To illustrate its possibilities with cheap power, a rather interesting case is that of Davos Platz, in Switzerland, a town having a total of about 5,000 inhabitants. Power is obtained from neighbouring waterfalls, from which 15,000 H.P. is available, and with this the total lighting and heating of the town is effected, the cost per kilowatt-hour being one-third of a penny.

One of the chief determining factors of the price per k.w.-hour is the cost of labour, a quantity which, judging from the present outlook, seems capable of very slight reduction. Another more serious factor is the conversion efficiency from lbs. of coal to k.w.-hours, which may be taken at about 10·15 per cent. Taking the efficiency of the dynamo and switch-gear at about 75 per cent., we have the total efficiency of the conversion from coal to electric heater as 7·6 per cent. It must be admitted that this is a very poor efficiency, but it is quite possible that in the near future it may be considerably increased. Compared with gas, however, the disparity does not appear so great, as will be seen from the following figures. When burnt under suitable conditions, 1 cubic foot of gas is capable of rendering 170,000 calories. A gas range is credited with an efficiency of about 15 per cent., so that 1,000 cubic feet of gas burnt in a range would give 25,500,000 effective calories. Allowing that 1 k.w.-hour of electricity = 857,143 calories, and the efficiency of an electric heater as 85 per cent., then the effective calories would equal 728,572. Therefore the proportion between the effective calorific values of 1,000 cubic feet of gas and 1 k.w.-hour of electricity is about 35 : 1. According to this, with gas at the present price of 2s. 4d. per 1,000 cubic feet in Manchester, apart from all other considerations, electricity will have to be sold at 0·8d. per unit for heating purposes. Although this ratio of costs does not always hold good, it will be found to be a fair average value.

It will now perhaps be advisable to consider the various systems in use at the present time, and to investigate as to how nearly they fulfil the ideal conditions of heating.

We are all more or less familiar with the ordinary carbon filament electric lamp, and although it is regarded as being primarily a source of light, yet only 3 to 5 per cent. of its energy is converted into light, the rest being spent in heating up the filament to a temperature sufficient to cause it to emit the luminous rays. In the first types of electric heaters the heat given out by these lamps was used, a lamp sometimes being fixed on a stand so that the water vessel, which had a recess in the bottom, could be placed over it. This method has, however, been found to be impracticable, and it has consequently been almost, if not entirely, abandoned.

In some of the later forms of apparatus, coils of resistance wire, packed in powders of various compositions, were tried, but these also are not now used to any great extent. A further advance of some importance was made by fixing the wire in close proximity to the heating surface by means of asbestos powder mixed with silicate of

soda. Usually water vessels had a false bottom, to allow for the space taken up by the pasted wire, and also to allow for packing underneath. The packings which are used at the present day are powders of grey and white asbestos, ponderous calc. magnesia, silica, glass, Calais sand, and cotton silicate. The chief reasons for discontinuing the use of asbestos paste are that it has a low resistance when cold, due partly to its being hygroscopic, and that it is a bad conductor of heat. For the last few years attention has been directed to the use of enamel similar to that used very largely for permanent signs and enamelled ironware. This enamel has been found superior in many ways to most of the insulators which will stand high temperatures without melting or igniting. The enamel comprises two parts, the ground mass and the surface, which is the enamel proper. The ground mass may consist of silica (in the form of white sand or powder), crystallised borax (for fluxing), fluorspar and magnesium carbonate (which reduces fusibility). These are mixed in varying proportions, powdered and fused, then again reduced to a powder, and to this is added aluminium silicate (in the form of pipeclay) and pure powdered quartz.

The enamel proper consists of flint meal (which is composed of quartz and silicates of iron and aluminium), also tin oxide, saltpetre, ammonium carbonate, lead sulphate, magnesium sulphate, potassium carbonate, borax, and sometimes gypsum and arsenic. These are mixed in carefully proportioned quantities, as too much of one will make the enamel crack off, and too much of others will make the fusion point too high or too low. A great deal of experience is necessary to get a satisfactory enamel combining the right qualities and also good insulating properties at temperatures within reasonable limits. The insulation resistance varies enormously with temperature, in some cases being 40 megohms when cold, but dropping to about 1,000 ohms at 400° C. Most of the enamels melt at about 900° C.

Some of the early enamels were of a composition closely resembling glass, and when a fair temperature was reached this melted, allowing the wire resistance to float about the surface of the metal base, until the connections, which were the heaviest parts, sank, and so short-circuited on the base. Other enamels, when subjected to a moderate temperature, cracked and lifted off, and there being nothing to carry away the rapidly generated heat, the wire fused. In other cases where the insulation resistance was very low when hot, such a large current went by way of the frame and enamel that the latter fused, setting up an arc between the wire and frame.

There are many reasons for using enamel on iron, the most important of which is the very slight disparity between the expansion coefficients of iron and enamel, whereas between that of copper and most of the other metals and enamel it is very much greater. The expansion coefficient for 1° C. for cast iron is 0·000010, for sheet iron 0·000011, and that for enamel 0·000009, but that of copper is 0·000017. This, then, shows that it is best to use cast iron together with enamel, as the difference between their coefficients is so slight, being

only 0·000001, although the insulation resistance of similar enamels is found to be better on wrought iron than cast.

In some types of heaters the ground enamel is laid next to the heating surface, the resistance wire being then laid on this in the correct position, and finally the surface enamel is fired on. In order to get a long length of wire into the small area of the heater, the wire is crimped, and lugs are fixed to the ends to which connection can be made easily when the wire is embedded. In many cases when using this type for water utensils, the heater is made into the form of a cast or wrought iron disc, which is then soldered on to the bottom of the vessel, a good heat-conducting surface being ensured by heating the disc (by means of a current being sent through it) to a temperature sufficient to float it in the solder melted on the inverted bottom.

In another type of heater only a ground enamel is used, but this is of a much finer composition than the previous one, the metallic resistance being composed of a very thin film of platinum, which is laid on the enamel surface. Under the same patents of the "Prometheus" Company a form of heating unit is made which is specially suitable for articles requiring temperatures up to 450° C. These heating units are composed of strips of mica about $\frac{4}{1000}$ of an inch thick, on which is painted a film of gold or platinum, sometimes only $\frac{1}{4500}$ of a millimetre thick, being at this thickness quite transparent. The metals in the form of powders are mixed with a flux and then painted on the mica, after which the whole is subjected to a high temperature, the finished films sometimes being produced of 100,000 ohms resistance, each being made to consume not more than 70 watts, this giving a temperature of about 450° C. To prevent injury to the film it is covered with another strip of mica, and then totally or partly enclosed in a thin metal frame. The insulation resistance of these strips is from 50 to 300 megohms, and the increase in the resistance of the foil varies from 10 to 20 per cent. during a period varying from 1 to 8 minutes. When used for warming rooms, these heating units are fixed in a metal framework which connects them in parallel, so that if one breaks down the others will still continue to be in circuit. For water vessels, long units are bent into a circular form and the two ends are fastened together by means of screws and nuts which serve to hold it in position and make good heat contact between it and the sides of the vessel. For such articles as hot-plates, flat-irons, etc., the heaters are pressed by means of screws and asbestos pads on to the heating surface.

In the Parvilée and Le Roy systems a very different heater is used. These heaters are either composed of a mixture of silicates and metals, cast into bars, or of bars of agglomerate silicon. The former are usually exposed to the air, while the latter are enclosed in glass bulbs with the air exhausted from them. These bars of metallo-ceramic composition can be made of any desired resistance, and to ensure good electrical contact, brass springs, which take up the expansion, are brazed on to the ends. Each bar is about 7 in. × $\frac{1}{2}$ in. × $\frac{1}{8}$ in., and is made to consume from 400 to 500 watts, attaining a cherry-red heat. This appears to be an ideal system in many respects for certain classes

of work. For warming rooms the bars can be fixed in suitable frames, so that they will be open to the air, emitting a cheerful glow like that of an ordinary fire. For grilling they can be fixed in a vertical or horizontal position either above or below the food, as the heat is both radiated and convected. When used in stoves for boiling liquids, the bars are placed in porcelain containing vessels which reflect the heat upwards to the bottoms of the pans or kettles, which are fitted with recesses in the top to allow the heat to be well absorbed by them.

In the Schindler-Jenny system the resistance, usually composed of wire, foil, or tape, is formed into the required shape and covered with porcelain clay, after which it is fired in a furnace, and then round the whole is cast a metallic shell of aluminium, copper, or bronze, which makes the whole a mechanically strong homogeneous mass. The units are made into various shapes according to requirements. For some radiators or convectors they are made flat with or without ribs, and for others they are made in a circular form with ribs on the circumference, connection being made to the resistance by three contact pins projecting through three holes in the shell.

The proportion of the amount of electrical energy which is sent into the various appliances to that which is usefully applied in the form of heat of course varies in the four systems above described, but it can be said that very high efficiencies can be obtained when using the most suitable methods. Radiators and convectors, of course, have 100 per cent. efficiency, as all the heat which is generated is finally spent in warming up the air. For flat-irons the efficiency cannot, of course, be given, as the amount of heat usefully employed cannot be measured, but for water utensils good results can be obtained. The following are the actual figures obtained by tests on a one-pint and a two-pint kettle: A two-pint single-jacket kettle containing two pints of water at 16·6° C. took exactly 9 minutes to boil, with a consumption of 792 watts. The amount of heat actually required to boil this 11·36 grammes of water would be 94,663 gramme-degree-calories, but the amount actually used for the operation was 102,500, the total efficiency being 92·25 per cent. The one-pint single-jacket kettle contained 600 grammes of water at 13° C., the boiling operation taking 7 minutes 7 seconds, with a consumption of 561 watts. The amount of heat actually required to boil this water would be 52,200 calories, but the amount actually used was 59,651, the total efficiency being 87·5 per cent. This lower efficiency is mainly due to the greater proportional radiation surface of a one-pint kettle. If a number of such operations follow closely upon one another, the heat latent in the metal after the first operation is added to the next, increasing the efficiency to 95 per cent. or more. A consumption of from 40 to 50 watts per square inch is usually allowed for the heaters used in water vessels, although only about 5 is allowed to keep them hot or nearly boiling. The efficiency can be increased by having double jackets to all the vessels, and also by keeping them highly polished, this making a difference of about 3 to 4 per cent.

If these water vessels are left in circuit while empty, the temperature of the disc rises to such a high value that the solder which fastens it to

the bottom melts, allowing it to fall off, and so the temperature rises still higher, and finally fuses the wire and enamel. This difficulty is now entirely overcome in some of the vessels by having a fusible cut-out in circuit, of which the following is a general description: In the centre of the heating disc (Fig. 1) is riveted a copper pin which has a collar in the middle with its face flush with that of the disc. The end of this pin T which is on the enamelled side of the disc is screwed to allow a cylindrical nut N, made of cadmium, lead, and tin, to be screwed over it, into the other end of which a contact bridge C is screwed. This bridge mainly consists of an insulated copper washer forming a connection between two springs, through which the current has to pass in order to complete its circuit. When the vessel is put on circuit while empty, the disc rises above its normal working temperature, and the heat is then conducted down the screwed copper pin to the fusible nut, which melts just above 100° C., allowing the bridge to fall into a brass cup provided for the purpose, and so breaking the circuit. The circuit is easily established again by screwing a new nut into position. To protect the discs and connections, and also to keep as much heat in as possible, a false bottom is soldered on, to which the feet are attached.

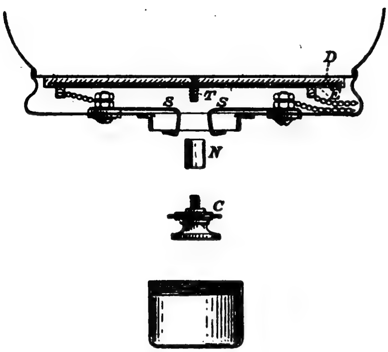


FIG. 1.

In many cases it is of course necessary to vary the heat given out by the apparatus, and this may be done by cutting out some of the circuits which are in parallel or by putting a resistance in circuit with the heater, which may be self-contained or external. The circuit changing may be effected by a many-contact resistance switch, by a number of plugs, or by one plug and many positions. Generally four heats in the proportion of 1 : 2 : 3 : 4 are quite sufficient, and may be obtained with two circuits only, one being of a comparatively low resistance and the other about twice as much. For the lowest heat the two circuits are in series; for second heat the high resistance only; for third heat the low resistance only, and for the highest heat the two circuits are in parallel. These different changes can be effected by one plug and socket. The resistances should be so disposed that the watt consumption per square inch of heater when on full heat is about the same all over the heating surface, and for this reason the circuits have sometimes to be divided into a number of parts.

Convectors or stoves for warming rooms, corridors, churches, offices, and cars are made in a variety of patterns, and in the case of the enamel system the convection area is increased by having artistic projections cast on the surface. For room warming 1 to 4 watts per

cubic yard per degree centigrade above the surrounding atmosphere is usually allowed, depending upon the height of the room and the number of people using it. Care should always be taken to place convectors where there is an incoming draught. The heating of cars, however, must be taken on a separate basis altogether, as the air rapidly changes, owing to the draughts carrying the heat away from the interior. Experts usually allow about 50 watts per person.

According to varying conditions regulation of the heaters is required, and this is sometimes performed by putting them in parallel or series. When heaters are used which are made up of a number of resistance spirals supported on porcelain insulators, they should not be placed where water dripping from the passengers' clothing can drop on the wires, as they quickly deteriorate under these conditions. Sometimes the convectors are placed in the bottom of the car, so that the air will be warmed in its passage through them. About 6 watts per square inch is usually allowed for the enamel type of convector, but those using metallic films on mica rather more than this. According to a paper read by Mr. J. T. McElroy before the Street Railway Association of New York, for car heating about 10 to 20 per cent. of the energy required for running is spent in the heaters, and the average of tests taken upon American cars with coal and electric heaters for 15-hour runs gave the price per day of 15 hours for coal as 9½d., and for electricity 9d.

At present, for room and office warming luminous radiators are very much in vogue, as no doubt the cheerful glow given out by them is as comforting as their actual warmth. The heating effect of these radiators is produced by the current flowing through a carbon filament 13 in. long and $\frac{1}{16}$ in. diameter, which raises it to a bright red heat. The filament, which is contained in an exhausted glass bulb about 8½ to 10 in. long, is bent in the middle to form a single loop, the ends being like an ordinary lamp connected to a bayonet cap or Edison socket. Each lamp is made to consume about 300 watts, and with from 1 to 5 lamps in each radiator very pretty effects can be obtained. Owing to the comparatively large currents which the contacts are required to carry, they are usually made of rolls of copper gauze with the ends left rough so that they will bed well.

If an iron of the enamel type which has been wired for a rather high watt consumption is left on circuit for any length of time without being used, it is liable to heat up to such an extent that its life is seriously impaired. To counteract this an ingenious contrivance has been invented which cuts off the current if the operator does not put it on the stand which is intended for it, or if he does put it on the stand, by means of a switch in the top of the latter a resistance is put in circuit with it which reduces the current to about one-half. To prevent as little loss as possible the series resistance is wired in the stand. The contrivance which switches off the current when the iron is put out of the operator's hands reduces fire risks to a minimum. Irons are made in a variety of patterns, the weights varying from ½ to 25 lbs., and from 20 to 25 watts per square inch of ironing surface

being allowed. In some cases the ironing blocks used by hatters, tailors, and embossers are also heated electrically.

One of the most important articles for domestic use is the electric oven, which is capable of very large development. The most important types of ovens employ either hot-plates of special design, metallo-ceramic bars or wires wound on porcelain tubes to dissipate the heat. A rather ingenious oven is constructed in a circular form, made so that it can be rotated about the central support. On this support are constructed a number of circular shelves divided into segments, each segment being controlled by a separate switch and heater, and in some cases there is an upper as well as a lower heater, so that the former can be lowered near to the food. The object of having this construction is so that a large or small quantity of food can be cooked at one operation, and can be more easily examined by bringing each segment before the main door.

Another important method of electric heating is by means of the arc, which is largely used in many commercial processes. It is applied

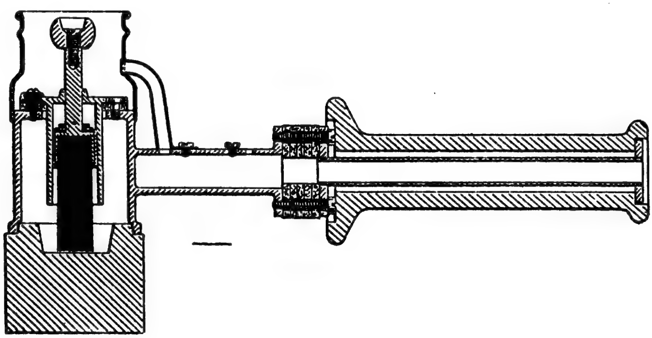


FIG. 2.

to a few domestic appliances, such as electric flat-irons and radiators. For packing-case makers and canning factories soldering-irons are made which are heated by the arc in their interior, which plays between a carbon rod and the large copper bit (Fig. 2).

Professor Ougrimoff, of Moscow, has designed a large water heater of 98 per cent. efficiency. This heater consists of a crucible of cast iron, in the bottom of which is placed powdered graphite. In this crucible, and regulated by a wheel and screw, is a large carbon rod which forms the positive pole, the crucible being connected to the negative pole, so that when the arc is set up the greater heat is produced on the graphite surface, and short-circuits are prevented by the resistance of the graphite. The heating chamber, which chiefly consists of the crucible, is, with the exception of the top, surrounded by the water to be heated, thereby preventing much loss.

The arc is also used in various types of furnaces for metallurgical work. In the Bernados and Zerener processes the arc is used for

filling up with metal the blow-holes which appear in iron castings, also for welding the seams of tubes and plates. For experimental purposes temperatures up to 2,000° C. have been obtained by passing a strong current through a tube of iridium, raising it to a white heat.

A type of furnace has been lately developed which derives its heat from the large currents produced in any metal by a fluctuating magnetic field, the lines of force of which are made to cross the metal. The crucible is made in a circular trough form, into which is poured some molten metal, thus forming a ring over which is piled the ore or metal to be treated. After a certain time has elapsed the ring melts and attains such a temperature that ores above it soon melt. Both Thomson and Kennedy have worked on the above principle.

Another method of raising bars of metal to a welding temperature is to dip them into a lead-lined tank containing an aqueous solution such as potassium carbonate or borax. The heat caused by the current through the high resistance film of hydrogen evolved at the positive pole, to which the rod of iron is connected, soon raises it to a temperature sufficient to melt the metal and cause it to run off from the end of the bar.

In conclusion it may be said that heating by electricity has certainly proved itself superior in most respects to any other method of heating, its chief drawback at present being the cost of electrical energy, which will satisfactorily decrease as the number of consumers increases, a state of affairs which could be more quickly brought about if more interest was taken in this particular branch of the electrical industry.

There is certainly a good opportunity for the electrical departments of corporations to open establishments for the loan of electric heating and cooking apparatus similar to those of the gas departments of some of our large cities, special reductions being made for summer loads.

I take this opportunity of expressing my thanks to my friend Mr. A. R. Wood for his kind assistance in carrying out some of the tests, and also to the following gentlemen and firms for the information and apparatus they have kindly placed at my disposal for illustrative purposes: Professor Ougrimoff, of the Ecole Polytechnic du Moscow; M. Levylier, of the Société de Chauffage par Electricité; Mr. J. I. Ayer, of the Simplex Electric Heating Company; Mr. W. Morrison, of the British Prometheus Co.; The General Electric Co., Ltd.; Parvillée Frères et Cie, and Messrs. Isenthal & Co., Ltd.

EQUIPMENT OF A GENERATING STATION, WITH SPECIAL REFERENCE TO THE CHELSEA STATION OF THE UNDERGROUND ELECTRIC RAILWAY.

By RICHARD F. CHAFFER, Student.

(*Abstract of Paper read before Students' Section, March* 29, 1905.)

Owing to the rapid increase of capacity in modern generating stations, and the diversity of opinion governing the design of large plants, the author proposes only to touch upon the general features affecting the design, and then to proceed to give a detailed description of the power-station of the Underground Electric Railways' Company. The first point to be considered is the position of the station in respect to the area of the distribution of energy. The ideal case, of course, is to locate the station in or near the centre of the supply area, but as the schemes of the present day are being applied to cities already built, the capital cost of ground would be out of the question. It is, therefore, found most economical to place the station as near the system as possible consistent with the capital cost of ground, and the cheapest and most reliable supply of coal and water.

The energy generated at the main station is distributed to substations, which are conveniently situated in the area of supply, and these in turn distribute the energy to the consumers. High voltage transmission is employed between the main station and the substations to keep down the capital cost of the cables. In Great Britain, where the distances of transmission are not large compared with the distances in Italy and America, voltages up to 11,000 volts are used. In large schemes alternating-current generators, generally of the three-phase, revolving field type, are usually employed.

In the choice of prime mover for the generators, steam turbines are coming more into favour, owing to their lower capital cost, and to the fact that they occupy less floor space. Hence the cost of buildings is less as compared with that required for vertical or horizontal steam engines of the same power; but the steam turbine has little or no advantage over the steam engine in point of steam consumption per kilowatt hour.

With regard to the rating of the generating units, these seem to be on the increase, and as a general rule are between 1,000 k.w. and 5,500 k.w. The usual practice is to instal two or three generators having about half the output of the large machines, the reason of

this being that the small generators take the day load in the case of a lighting station, and when the load increases sufficiently the large machines are started up. By this means the generating units are run at their most economical loads, and as near their maximum output as possible. Simplicity in the arrangement of the station is essential, and the most favoured plan is to arrange the plant on the complete unit system.

Having now mentioned a few of the main points in central station design, and as the characteristics of the stations vary with the different loads, such as lighting and power, traction, and mixed stations, also with the local conditions, the author will describe in detail a station designed for traction only.

The Chelsea station, when complete, will supply the power necessary for the working of the southern half of the Inner Circle, which it is working in conjunction with the Metropolitan Company's power-station at Neasden, and for the whole of the District Railway. It will also furnish power to the Baker Street and Waterloo, and the Great Northern, Piccadilly and Brompton Tube Railways on their completion. The electrical capacity of the station at normal load is 57,000 kilowatts, and on this basis the cubic feet capacity of the building per k.w. is 139, and the square feet per k.w. is 1·36.

The station occupies a site of 3·67 acres on the north side of the Thames at Lots Road, Chelsea, with a water frontage on the Thames and Chelsea creek of 1,100 feet, and a frontage of 824 feet on Lots Road. It is admirably situated as regards facilities for coal supply, as it is in the immediate vicinity of a railway siding, and coal can also be brought up the river in barges, and it is upon this latter means of communication that the station mainly depends. The main building is 454 feet long by 175 feet wide, and is 140 feet in height measured from the basement to the apex of the boiler-house roof. It has a self-supporting steel frame, weighing about 6,000 tons, and this is filled in with bricks faced with terra-cotta. The flooring throughout is of concrete and expanded metal, except in the case of the engine-room, where the floor is formed of steel chequer plates. There are none of the ornamental features usual to municipal undertakings, as the station was built on purely commercial lines, and simplicity was aimed at.

A large basin or dock is provided, which is capable of receiving six full-sized barges at one tide. This dock is spanned by two travelling gantry cranes, each crane working a 27 cwt. grab bucket, which deposits the coal into a hopper at one end of the crane where it is automatically weighed. The coal falls from the hopper on to a belt conveyor which carries it to the foot of the elevator tower, where it is automatically tipped. It is then carried to the top of the boiler-house by means of two inclined elevators, consisting of two endless chains of buckets working side by side, which deliver the coal to two endless belt conveyors running the entire length of the boiler-house; the coal is distributed evenly over the bunkers by means of an automatic tipping carriage which travels slowly from end to end of the boiler-house. It falls through shoots down to the hoppers of the mechanical stokers as

required from the bunkers which have a storage capacity of 15,000 tons. At normal load the boilers are estimated to consume 800 tons of coal per day.

The ash accumulates in hoppers underneath each boiler, and thence descends through shoots to an ash railway in the basement which conveys it to a pocket where it is stored until removed by barges. Thus the entire coal-handling plant is wholly automatic from the moment the coal leaves the barge until it is returned to the barge as ash.

The boiler-house is 100 feet wide, and consists of a basement and two floors. On the basement or ground floor there are eight boiler feed pumps, seven of these being Blake and Knowles, and one Heizler pump; also the ash railway mentioned above. The boilers are on two floors, each containing thirty-two boilers, with space available for eight more on each. They are divided into batteries, each battery consisting of eight boilers. One feed pump is provided for each battery of boilers, which is supplied with steam from the battery to which it is attached. There is no interconnection between the batteries except in the case of the three batteries at the east end of the boiler-house, which are connected to a supplemental header, for supplying steam to the exciter sets, air compressor, house pump, etc. The boilers are of the well-known Babcock and Wilcox water-tube type, with 5,212 square feet of heating surface, and 672 square feet of superheating surface. They are fitted with Babcock chain-grate stoking gear, actuated by eccentrics off lines of shafting laid underneath the floors which are driven by induction motors. Each battery is fitted with economisers for heating the feed water, situated behind the boilers immediately over the flues, and provided with the usual by-pass arrangements to the chimneys. There are four chimneys, 19 feet internal diameter, and 275 feet high. The foundation of each of these chimneys is 42 feet square, and 32 feet 6 inches below the ground level, and each contains 2,200 cubic yards of concrete. The main steam pipes from each battery of boilers are taken through the wall into the engine-room basement, and go direct to the turbines which they supply.

The engine-room is 75 feet wide, and is the same length as the boiler-house. It has a basement underneath, and one floor above. The generating sets are erected on large concrete pier foundations built up from the basement to the level of engine-room floor. There are eight 5,500 k.w. generators installed which are direct coupled to Westinghouse steam turbines developing 7,400 H.P. These turbines are of the horizontal axial flow type, in which the steam is admitted at the centre of the rotor casing and flows towards each end, thus eliminating all end thrust due to steam pressure on the blades. The expansion of the steam is carried out by lengthening the blades in sets gradually as they near the end of the casing. To prevent end play of the rotor, and hence fouling of the fixed and moving blades, a number of collars are turned on the shaft which fit into an adjustable thrust block, thus allowing the rotor to be set in its correct position relatively to the fixed blades.

The main bearings of the turbine and generator are of the spherical or self-aligning type and are of the most massive and solid construction, each bearing weighing 8 tons. They are water-jacketed to keep them cool in addition to the system of forced lubrication employed. Oil is pumped through all the bearings and journals under pressure, thus ensuring efficient lubrication, and after passing through the bearing it is pumped back to the oil-house outside the building, where it is cooled, filtered, and again passed through the bearings. The turbines are connected to the generator by means of a claw coupling, which allows a slight lateral movement of the generator and also allows for the expansion of the turbine shaft due to heat. The method of allowing for the expansion of the turbine (which is considerable) is as follows :—The end of the turbine casing nearest to the generator is bolted firmly to the bed plate and the sides of the casing parallel to the shaft are held down to the bed plate by guides, somewhat similar to the slipper guides of an engine crosshead, while the end furthest from the generator is not impeded in any way as the outer bearing is carried by the turbine casing; thus it will be seen that the whole casing can expand in one direction only, on the bed plate, without altering the relative positions of turbine and generator.

The generators are three-phase, revolving field type, and are the largest yet built, the total weight being about 90 tons. The armature unwound weighs 50 tons and the armature winding weighs 3 tons. Each machine is designed to give 290 amperes at 11,000 volts at $33\frac{1}{3}$ cycles per second, the speed being 1,000 r.p.m. The revolving fields are made of wrought-iron forgings built up in sections, and the winding is of copper ribbon 2-in. × $\frac{5}{64}$-in. laid into slots and secured there by phosphor-bronze bars. Fig. 1 shows an armature being wound *in situ*, while Fig. 2 shows the completed armature. Fig. 3 shows the completed revolving-field magnet.

Heavy gun-metal slip rings and carbon brushes convey the exciting current into the winding, and the ends of the field are closed with turned brass discs to keep down the windage loss, as this would be considerable in machines of this size and type. These generating sets are capable of sustaining a 50 per cent. overload for two hours at practically normal load steam consumption per kilowatt-hour. The exciting current for the generators is furnished by four 125 k.w. direct-current generators, which are direct-coupled to compound vertical engines running at 375 r.p.m. These supply current for the arc lamps in the building, and for a few direct-current motors (about seven) in addition to that needed for the excitation of the generators.

The condensing system for the main units and auxiliaries consists of eight vertical surface condensers, each having a cooling surface of 15,000 square feet. They are placed in pits running up the centre of the engine-room, with one condenser almost below each turbine. The steam from each turbine is carried to the condenser by two 44-inch exhaust pipes, provided with automatic relief valves so that the turbine may exhaust into the atmosphere if necessary. These large valves are operated either by pneumatic motors or by hand. The circulating or

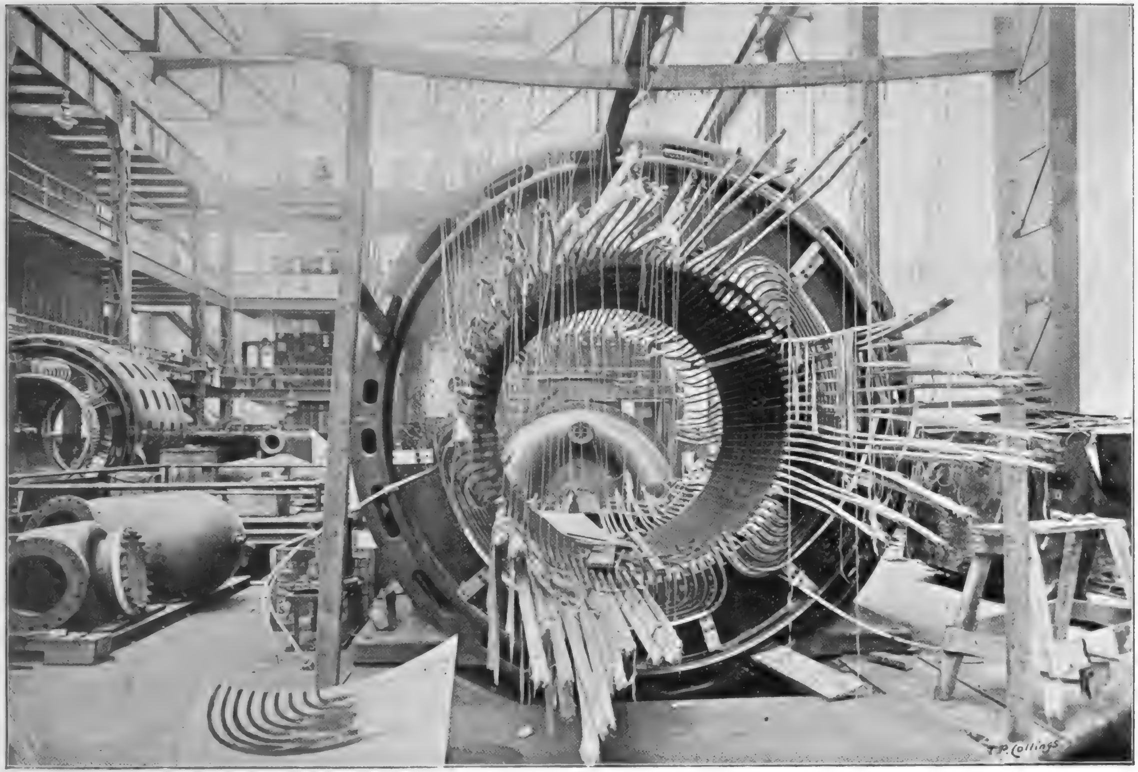


FIG. I.

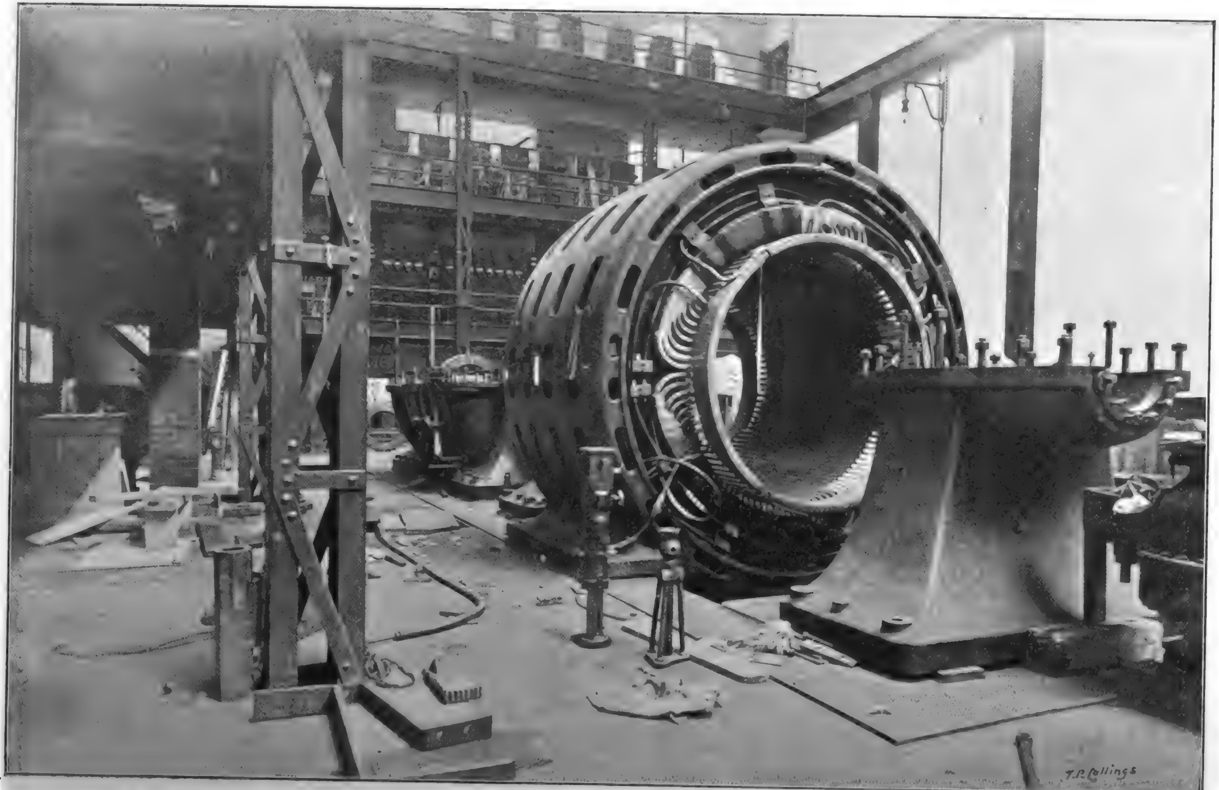


FIG. 2.

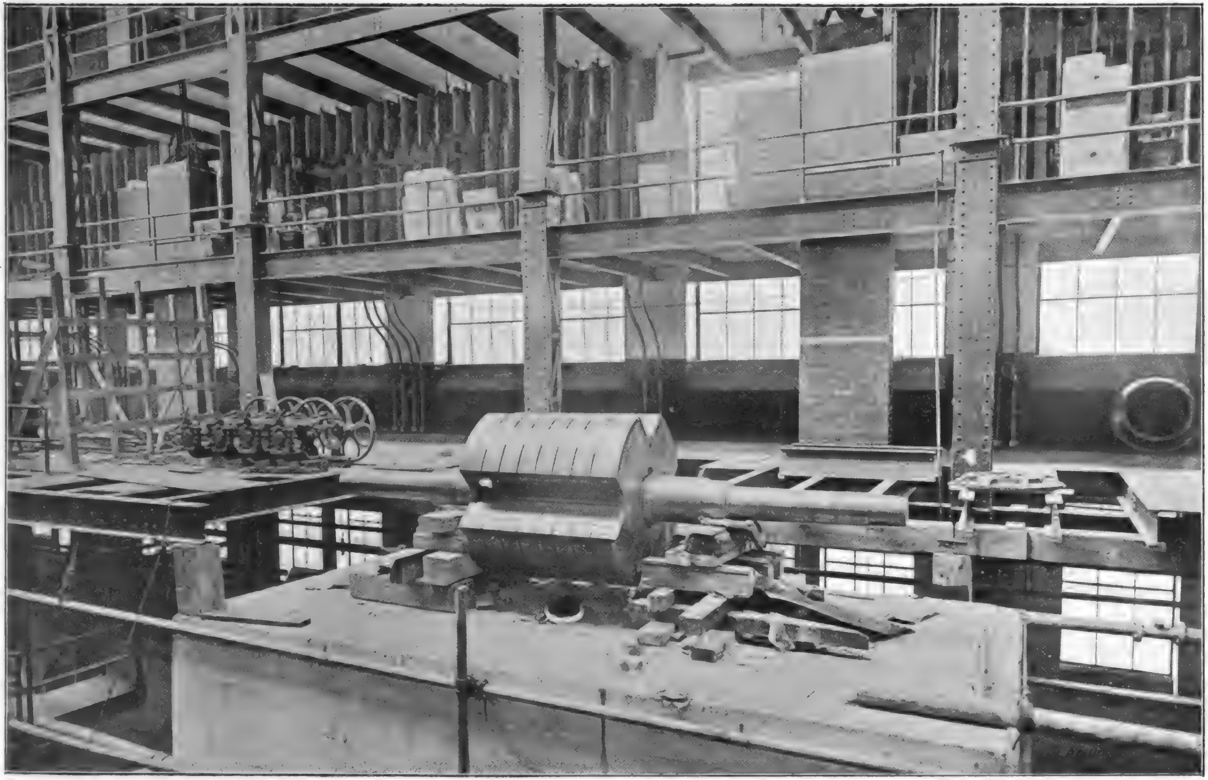


FIG. 3.

cooling water is arranged on a very ingenious system. The water is supplied by two 66-inch pipes which run along beneath the condensers, and are laid to the edge of the navigable channel of the Thames, thus ensuring a plentiful supply of cooling water. These pipes are arranged for reversible flow, the reason being that if the suction pipe becomes choked by mud or silt from the river bed, it can be cleaned out again by reversing the flow. Each condenser has a 20-inch centrifugal pump for the circulating water, the duty of this pump being merely to overcome the friction in the pipes, as the tops of the condensers are within 29 feet of minimum low tide, and the pipes are arranged on the syphon principle. The condensers are designed to work on the dry vacuum principle, *i.e.*, the air-pump for obtaining the vacuum, and the water-pump for removing the condensed water are separate; all pumps in connection with the condensers are driven by induction motors.

The most interesting feature of the whole station is the switchboard and control system, as it is the first of its kind in Great Britain. This system aims at having the entire control of the plant and switch gear in a small space, and at the same time having no high tension or dangerous voltages on any part of the control board. The outline of this system of remote control is as follows:—All high-voltage switchgear is operated by small direct-current motors situated on the top of the switch proper and well away from all parts of the switch at a high potential. These small motors are operated by single pole switches from the control board, so that the only current carried by the control board is direct-current at a low voltage (in this case 125 volts). This system was, the author believes, first adopted by the Westinghouse Co. in the Niagara Falls Power Co.'s plant in America and is very successful, while the sense of security enjoyed by the operator while controlling these high voltage switches from a distance ensures confidence, which is so essential in dealing with huge plants of this description. The whole switchboard is carried by three galleries extending the whole length of the north side of the engine-room and continued along the east end as well. The lower gallery contains the lightning arresters or static dischargers and the main generator switches; on the middle gallery are the main bus-bars and bus-section switches, and on the top gallery are all the feeder switches and the subsidiary or group bus-bars. The centre of the middle gallery projects slightly outwards over the engine-room for about 30 feet of its length, and on this is situated the generator control board, while behind this is the feeder control board.

The current from each generator is taken by cables up to the generator switch on the lower gallery, and after passing through this switch it goes direct to the main bus-bars on the middle gallery. These bus-bars extend the whole length of the gallery, and are contained in brick tunnels with artificial stone divisions between each phase, and provided with iron doors every few feet for inspection. The bus-bars are divided into five sections by bus-section switches, and two generators are connected to each bus section; from these bus sections cables run up to the top gallery, and after passing through group switches, go

direct to group or subsidiary bus-bars which are eight in number and are similar to the main bus-bars. Six feeders are attached to each group of bus-bars to form a group, and after passing the feeder switches the cables are run to the lower gallery in artificial stone channels, and are there connected to the static dischargers, and then joined to a 3-core lead-covered cable. The static dischargers consist of a large number of small gaps and carbon rods which will discharge any static electricity that may be in the cable, but will not pass a power discharge. The cables are then run to the basement where they are laid in conduits which convey them to Earl's Court, that being the nearest point on the system, and they are then placed in racks along the sides of the tunnels. At each substation the voltage is transformed down to about 365 volts by air-blast transformers, and this voltage is applied to the alternating-current side of rotary converters which convert to direct current at 550 volts.

On the control board on the middle gallery, the generator panels claim first attention. There are eleven generator panels of the desk type, but only eight are in use, the remainder being spare or for use when the capacity of the station is increased. On each panel there are the control switches for the generator switch, group switch, engine governor, field rheostat, and the field switch, a synchronising plug, and every alternate panel has a bus-section switch and bus-section synchronising plug. The engine governor switch operates a small motor inside the governor casing which moves the counterweight back or forward, thus varying the speed. The field rheostat controls a small motor which is geared to a worm-wheel and moves the finger over the studs of the rheostat, thus cutting out or putting in resistance. The switches are provided with red and green pilot lamps indicating whether the main switch is open or closed. The instruments are situated immediately over the switch panel, and each instrument panel has three ammeters, one in each phase, a power-factor indicator, a wattmeter, a voltmeter, recording wattmeter, and an ammeter in the field circuit, while there is a synchroniser on a swing bracket at each end of the board.

Immediately behind the generator board is the feeder board, for controlling the feeder switches mentioned above. There are sixteen panels, each panel having four small double-throw single-pole switches. Only two of these feeders on each panel are used, the remaining two being duplicates. Twelve time-limit relays are fitted on each panel, one in each phase of each feeder cable; these perform the work of circuit breakers on a D.C. system, *i.e.*, the circuit is broken the moment an overload or short circuit occurs. If a heavy current due to a short circuit occurs, it causes an iron solenoid to rise inside the relay, and this completes the switch-motor circuit and opens the switch. They are known as time-limit relays on account of an arrangement by means of which they can be set to act only after the elapse of the set time, generally a few seconds. If one of the feeder switches is opened by a relay a gong starts ringing and only stops when the switch is put back. The relay also lights a pilot lamp on the generator panels indicating in which group the faulty feeder is.

There is an ammeter and a recording wattmeter for each feeder on the feeder panels. All the instruments on the control board are attached to series and potential transformers so that no high voltages are carried by them. Reverse-current relays are fitted to each generator switch and these light up an indicating lamp on the generator panel.

On the lower gallery at the east end of the engine-room are the auxiliary panels for the exciter sets, a panel for a 125 k.w. motor generator for charging the cells used for the switch motors. Also there are panels for the motor circuits and part of the lighting. All the current on these boards is low tension at 220 volts. The middle gallery contains the field rheostats, and these are driven by small motors operated from the control board, and are geared through a worm and worm-wheel to the switch finger. The motor and fan for the air-blast transformers is on this gallery. There are nine transformers on the top gallery of 166 k.w. capacity, which transform from 11,000 volts down to 220 volts for use in the station. All the motors in the building are induction motors with the exception of the crane motors in the engine-room, and the incandescent lighting is all on the A.C. side.

The engine-room is spanned by two 18-ton travelling cranes, and there is also a 35-ton jib crane outside the engine-room at the west end, which was used for lifting all the machinery on to the engine-room floor, which is 18 feet above the ground level.

Attached to the engine-room is a suite of general and engineers' offices. There is also a very complete test-room and a large repair shop.

In conclusion, the author desires to express his thanks to Mr. J. R. Chapman, General Manager and Chief Engineer, for permission to publish the descriptive details and illustrations, and to Mr. Biettely for the trouble he has taken for preparing slides. He is also indebted to Messrs. Gordon and Tresilian for the use of their negatives.

The Thirty-third Annual General Meeting of the Institution of Electrical Engineers was held in the Library, 92, Victoria Street, W.C., on Friday, May 26, 1905—Mr. ALEXANDER SIEMENS, President, in the chair.

The Secretary having read the notice convening the meeting, the Minutes of the Ordinary General Meeting held on May 25, 1905, were read and confirmed.

Messrs. F. Pooley and R. P. Wilson were appointed scrutineers of the ballot for the election of new members, and, at the end of the meeting, the following were declared to have been duly elected :—

Associate Members.

Harold Hargreaves Beare.
Edward Cross.
William Emmanuel M. Curnock.
Edward White Edwardson.
Mitchell Hickman.
Frederick George Jones.
Karl Konow Krogh.
William Allan Macfarlane.
Edward Rayner.
Sidney Frank Ricketts.
Henry Shaw.
William Irwin Tarleton.
Harry Winthrop Turner.
Albert Vaux.
Percy A. Yapp.

Students.

John Clifford Alleyne.
Harold Adair Armitage.
Edward Barry.
George Brooks.
Alan Wingfield Bullough.
Albert Edmund Clayton.
Charles Edward Crossley.
Hormasjee Ratanshaw Dadabhoy.
Frederick George Davies.
George Herbert Gill.
Edward Arthur F. Goodfellow.
Herbert Hastings.
William Charles Kennett.
James Herbert Kummer.
Edgar Lockwood.
Robert Sawers, Jun.
Edward John Wheen.
Herbert F. Gunnell Woods.
Felipe Zapata.

The Report of the Council for 1904–5 was then presented, and was read in abstract by the President.

REPORT OF THE COUNCIL PRESENTED AT THE ANNUAL GENERAL MEETING OF MAY 26, 1905.

At this the Thirty-third Annual General Meeting of the Institution of Electrical Engineers the Council present to the members their Report on the Proceedings of the Institution during the Session 1904–5, and are glad to note that the Institution continues to increase in numbers and in importance and that the progress made is highly satisfactory.

Growth of the Institution.

Since the last Annual General Meeting to May 26, inclusive, there have been elected 12 Members, 171 Associate Members, 20 Associates, and 292 Students, making in all a total of 495 accessions.

To the class of Members there have been transferred 31 Associate Members, and 13 Associates; to the class of Associate Members, 57 Associates and 10 Students, and up to the end of December, 1904, 5 Students had been transferred to the class of Associates. The increase in membership during the past year may be seen from the following tabular statement, which gives the number of members on the roll of the Institution at the end of the session 1904, and at the corresponding period in the current year :—

	1904.	1905.
Honorary Members	6	6
Members	965	994
Associate Members	1,435	1,610
Associates	1,761	1,609
Students	1,107	1,321
Foreign Members	136	131
Total	5,410	5,671

It has been thought desirable by the Council to pass Standing Orders that no candidate shall in future be elected or transferred to the class of Associates who may be eligible for election or transfer to the class of Members, Associate Members, or Students. Students or candidates professionally engaged as Electrical Engineers can therefore no longer join the class of Associates, which, in accordance with the terms of Article 15 of the Articles of Association, is reserved for persons who are so associated with the application of electricity that the Council consider their admission as Associates would conduce to the interests of the Institution.

The Council have had occasion during the past year to congratulate several members of the Institution who have had high distinctions

conferred upon them. During 1904 Sir James Dewar, F.R.S., and Sir Joseph W. Swan, F.R.S., Past-President, have received the dignity of knighthood, and the Hon. C. A. Parsons, C.B., F.R.S., Past-Member of Council, has had conferred upon him the Order of the Companionship of the Bath. Sir Joseph W. Swan has also been awarded the Hughes Medal of the Royal Society. The Right Hon. Lord Kelvin, O.M., G.C.V.O., F.R.S., Past-President, has been elected Chancellor of the University of Glasgow in succession to the late Earl of Stair, K.T., and has been chosen as the most worthy recipient of the John Fritz Medal on the occasion of its first award. The medal was founded in recognition of the achievements of Mr. John Fritz in Industrial Progress, and the award was made by a Board selected from the members of the four leading technical institutions in America.

Election of Honorary Member.

The Council, in conformity with Articles 11 and 17 of the Articles of Association, have in the past Session elected as Honorary Member of the Institution Professor Elihu Thomson, Past-President of the American Institute of Electrical Engineers. Professor Thomson filled the office of President of the International Electrical Congress held at St. Louis in September, 1904, and his celebrity as an inventor in the field of electrical science is world-wide.

Deceased Members.

During the past year the Institution has suffered exceptionally heavy losses by the death of several well-known members. The following are the names of the deceased members:—

Honorary Member.

Major-General C. E. Webber, C.B., Past-President.

Members.

John Bailey.
C. H. Gerhardi.
C. Goldstone.
R. H. Housman.
J. G. Morrison.
L. H. K. Stotherd.
C. J. Sutherland.
E. Talbot.
E. T. Truman.
J. B. Verity.
T. J. Wilmot.

Associate Members.

F. C. Briggs.
A. C. Ford.
C. A. Gawthorp.
H. H. E. Heath.
J. M. Irvine
W. H. Smith.
R. O. Wright.

Associates.

W. R. C. Barrington.
H. Lindon.
J. A. Peggs.
S. Sherley-Price.
L. Stockdale.
A. H. H. Trott.
Col. H. Watkin, R.A.
Walter Wood.

The active interest taken by the late Major-General C. E. Webber, C.B., Past-President and Honorary Member, in the welfare of the Institution, of which he was one of the founders, is well known to all, and his loss has been keenly felt by his colleagues on the Council. Throughout his career his labours in the advancement of electrical science and for the protection of the interests of the industry in general were unceasing. He contributed to the Institution Proceedings many important memoirs on electrical matters, dealing chiefly with military telegraphs, of which he was one of the principal organisers in this country. Further particulars of his career are given in the Obituary notice, p. 584.

A handsome medallion portrait of the late Major-General C. E. Webber, carved in relief in white marble, has been presented by his brother, Mr. W. D. Webber, to the Institution. This memorial of their distinguished Past-President and Honorary Member was gratefully accepted by the Council, and is now suspended on the walls of the Library of the Institution.

Resignations.

Eight Members, ten Associate Members, two Foreign Members, thirty-one Associates, and twenty-seven Students have resigned since the date of the last Report.

Articles of Association.

As reported last year, the resolutions carrying out the change with regard to the period at which the President takes office were brought forward at a Special General Meeting on June 9, 1904, and were duly confirmed. The alteration has since taken effect, and the Council's anticipation of the advantage which would be derived by means of this arrangement, namely, that during the recess the business of the Institution can be more readily carried on by the President in concert with his successor, the President-Elect, has been amply fulfilled.

Work of the Institution.

During the past year there have been 21 Committees at work. 17 General Meetings, 19 Council Meetings, and 68 Committee Meetings have been held.

Papers.

In addition to the President's Inaugural Address, the following papers, read at Ordinary and extra Ordinary General Meetings, will be found in Volumes 34 and 35 of the Journal :—

1904.

Nov. 24.—"Hydrodynamical and Electromagnetic Investigations regarding the Magnetic Flux Distribution in Toothed Core Armatures," by Prof H. S. Hele-Shaw, F.R.S., Dr. A. Hay, Member, and P. H. Powell, Student.

Dec. 8.—"Studies in Magnetic Testing," by G. F. C. Searle.

" 15.—"The Combination of Dust Destructors and Electricity Works Economically Considered," by W. P. Adams, Member,

1905.
Jan. 12.—"Fuel Economy in Steam Power Plants," by W. H. Booth and J. B. C. Kershaw.
Feb. 9.—"The Value of Overhead Mains for Electric Distribution in the United Kingdom," by G. L. Addenbrooke, Member.
" 23.—"Type Setting by Telegraph," by D. Murray.
Mar. 9.—"On the Effect of Heat on the Electrical and Mechanical Properties of Dielectrics," and "On the Temperature Distribution in the Interior of Field Coils," by E. H. Rayner.
" 9.—"Temperature Curves and the Rating of Electrical Machinery," by R. Goldschmidt, Associate Member.
April 6.—"Report on the St. Louis International Electrical Congress," by W. Duddell, Member.
" 13.—"The Alternating-Current Series Motor," by F. Creedy, Student.
May 11.—"Telephone Traffic," by H. Laws Webb, Member.
" 25.—"Wireless Telegraphy Measurements," by W. Duddell, Member, and J. E. Taylor, Associate Member.

The following papers, selected from those read at Local Section Meetings, have been (up to the present) accepted for publication :—

BIRMINGHAM.

1904.
Nov. 23—"The Use of Iron in Alternate-Current Instruments" (delivered as an Inaugural Address), by W. E. Sumpner, Member.
Dec. 14.—"Standby Charges and Motor Load Development," by A. M. Taylor, Member.
1905
Mar. 15—"Notes on Heating and Sparking Limits in Variable-Speed Motors," by A. H. Bate, Associate Member.
" 15.—"Commutation in a Four-pole Motor," by J. K. Catterson-Smith, Student.
April 12.—"The Eddy Current Brake for Testing Motors," by D. K. Morris and G. A. Lister.

DUBLIN.

1904.
Feb. 11.—"Steam Turbines," by F. C. Porte, Member.
April 14.—"Notes on Solid Rail Joints," by P. S. Sheardown, Associate Member.
Nov. 10.—Abstract of Chairman's Address, by M. Ruddle, Member.

GLASGOW.

Nov. 8.—Abstract of Chairman's Address, by R. Robertson, Member.
Dec. 13.—"Armature Reaction in Armatures," by J. B. Henderson, Member, and J. S. Nicholson.
1905.
Jan 10.—"Street Lighting by Electric Arc Lamps," by H. B. Maxwell, Associate Member.
Feb. 14.—"Earthing," by W. W. Lackie, Member.
May 9.—"Alternating Current Motors in Industrial Service," by P. D. Ionides.

LEEDS.

1904.
Nov. 17.—Abstract of Chairman's Address, by W. Emmott, Member.
1905.
Jan. 19.—"Condensing Arrangements in Central Stations," by J. D. Bailie, Associate Member.
Feb. 16.—"Tramways Permanent Way Construction and Maintenance," by Jas. Lord, Associate Member.

MANCHESTER.

1904.
Mar. 16.—"Localisation of Faults on Low-Tension Networks," by W. E. Groves, Associate Member.
Nov. 18.—Abstract of Chairman's Address, by C. D. Taite, Member.
Dec. 13.—"High-Tension Switchgear," by L. Andrews, Member.
1905.
Jan. 17.—"The Electrical Operation of Textile Factories," by H. W. Wilson, Associate Member.
„ 26.—"Compensated Alternate-Current Generators," by Miles Walker, Associate.
Feb. 28.—"The Mechanical Construction of Steam Turbines and Turbo-Generators," by W. J. A. London, Associate Member.
Mar. 14.—"Low-Tension Thermal Cut-outs," by A. Schwartz, Member, and W. H. N. James, Associate.

NEWCASTLE.

1904.
Nov. 21.—Abstract of Chairman's Address, by E. Eugene-Brown, Member.
1905.
Feb. 27.—"Notes on Effects in Three-phase Working," by Dr. W. M. Thornton, Member.

The papers above referred to have been, or will be, printed in the Journal of the Institution, and, in addition, the following Original Communications have been approved for publication :—

"The Magnetic Properties of some Alloys of Iron and Silicon," by T. Baker, M.Sc.
"Shunt Resistances and Temperature Compensation for Ammeters," by A. Campbell, Associate Member.
"The Dissymmetry of a Three-phase System," by A. B. Field, Associate Member.

SALOMONS SCHOLARSHIP.

The Council has awarded three Salomons Scholarships, value £50 each, to :—

Mr. A. E. Clayton, of King's College.
Mr. E. A. F. Goodfellow, of the Central Technical College.
Mr. F. C. Prentice, of University College.

DAVID HUGHES SCHOLARSHIP.

Two David Hughes Scholarships, value £50 each, have also been awarded to :—

Mr. E. A. Biedermann, of the Finsbury Technical College.
Mr. J. B. Sparks, „ „ „ „

STUDENTS' SECTION.

Meetings of the Students' Section have been held in London and Manchester, at which papers have been read and discussed. Visits to the following places were arranged during the Session :—

1904.
Nov. 17.—The Great Eastern Railway, Stratford, E.
„ 26.—The Great Northern, Piccadilly and Brompton Railway Tunnelling Works.
Dec. 8.—The Robertson Electric Lamps, Ltd., Brook Green, W.

1905.

Jan. 21.—The India-rubber, Gutta-percha, and Telegraph Works, Company, Ltd., Silvertown, E.

„ 28 and Feb. 11.—The Central Telephone Exchange of the General Post Office.

Feb. 4.—Messrs. Evershed and Vignoles, Ltd., Acton Lane, W.

„ 25.—The Great Northern and City Railway Company.

Mar. 11.—The Napier Motor Car Works, Acton Vale, W.

„ 17 and 24.—The Board of Trade Laboratory, Whitehall, S.W.

April 15.—The National Physical Laboratory, Bushey House, Teddington.

May 11.—The Electrical Power Storage Company, Ltd., Millwall, E.

„ 20.—The Fulham Borough Electricity Works.

During the Easter holidays a visit was paid to the following works, in the neighbourhood of Leeds, in an excursion successfully organised by the Students' Committee, of which Mr. A. G. Ellis was Honorary Secretary :—

The Brush Electrical Engineering Company (Loughborough).
The Leeds Copper Works, Ltd.
Messrs. Greenwood and Batley, Ltd.
Messrs. J. and H. McLaren.
The Yorkshire Electric Power Company.
Messrs. John Fowler and Company.
Messrs. Graham Morton and Company.
The Farnley Iron Company.
The Phœnix Dynamo and Motor Company.

Annual Premiums.

The Council have awarded the following premiums for papers and communications :—

The Institution Premium, value £25,

to Mr. E. H. Rayner, for his paper "On the Effect of Heat on the Electrical and Mechanical Properties of Dielectrics," and "On the Temperature Distribution in the Interior of Field Coils."

The Paris Electrical Exhibition Premium, value £10,

to Professor H. S. Hele-Shaw, F.R.S., Dr. A. Hay, and P. H. Powell, for their paper, "Hydrodynamical and Electromagnetic Investigations regarding the Magnetic Flux Distribution in Toothed Core Armatures."

The Fahie Premium, value £10,

to Mr. D. Murray, for his paper "Type Setting by Telegraph."

Three Extra Premiums, value £10 each,

one to Mr. R. Goldschmidt, for his paper, "Temperature Curves and the Rating of Electrical Machinery"; one to Mr. Miles Walker

(Manchester Local Section), for his paper, "Compensated Alternate Current Generators"; and one to Messrs. D. K. MORRIS and J. K. CATTERSON-SMITH (Birmingham Local Section), for their paper on "Some Uses of the Oscillograph."

ONE EXTRA PREMIUM, value £5,

to Messrs. J. B. HENDERSON and J. S. NICHOLSON (Glasgow Local Section), for their paper, "Armature Reaction in Armatures."

AN ORIGINAL COMMUNICATION PREMIUM, value £10,

to Mr. A. B. FIELD, for his communication on "The Dissymmetry of a Three-Phase System."

AN ORIGINAL COMMUNICATION PREMIUM, value £5,

to Mr. T. BAKER, for his communication, "The Magnetic Properties of Some Alloys of Iron and Silicon."

STUDENTS' PREMIUMS.

The First Students' Premium, value £8, to Messrs. E. A. BIEDERMANN and J. B. SPARKS, for their paper on "E. M. F. Wave Forms."

The Second Students' Premium, value £5, to Mr. J. W. ANSON, for his paper, "The Present Electrical Equipment of the London County Council Tramways."

The Third Students' Premium, value £5, to Mr. A. C. ANDERSON, for his paper on "The Applications of Electricity in Mines."

An Extra Premium, value £4, to Mr. A. E. JEPSON, for his paper on "Electric Heating."

An Extra Premium, value £3, to Mr. R. F. CHAFFER, for his paper on "The Equipment of a Modern Generating Station, with Special Reference to the Chelsea Station of the Underground Railways."

In accordance with precedent, the Council, in making the awards of premiums, have not taken into account the papers contributed by present Members of Council. Papers other than those of the Students' Section which were not in type by the end of April, 1905, have been reserved for consideration in awarding premiums in 1906; but certain papers which were received too late for consideration in 1904 have been taken into account this year.

LOCAL SECTIONS.

The work of the Local Sections has been carried on during the past Session with conspicuous success on the part of the various Chairmen and Committees. The Council desire to place on record their appreciation of the services of the Chairmen and of the Honorary Secretaries in organising meetings and in the arrangement of visits and excursions to Works and other places of interest. Many valuable papers have been read which have in many cases led to interesting discussions, and the

Sections are to be congratulated on the excellence of the standard which they are maintaining.

The Annual Dinners of several Local Sections were very largely attended. At these the President and several Members of Council were able to be present, in addition to many local distinguished guests.

INTERNATIONAL ELECTRICAL CONGRESS.

In response to the invitation of the American Institute of Electrical Engineers to co-operate in the proceedings of the International Electrical Congress at St. Louis in September, 1904, the President and Council appointed the following Members to act as Delegates of the Institution at the Congress :—

Mr. Robert Kaye Gray, *President.*
Colonel R. E. Crompton, C.B., *Past-President.*
Professor John Perry, D.Sc., F.R.S., *Past-President.*
Dr. R. T. Glazebrook, F.R.S., *Member of Council.*
Mr. H. E. Harrison, B.Sc., *Past Member of Council.*
Mr. W. Duddell, *Past Member of Council, and Hon. Secretary to the Delegation.*

These Delegates attended the Meetings of Congress from September 12th to 17th, and took part in the discussion of the papers, many of which were of high importance and interest. The Council, in sending this delegation of eminent electrical engineers and scientists to St. Louis, were actuated by the desire to promote by all the means within their power the advancement of electrical science and knowledge, and they consider that in so doing the dignity and traditions of the Institution have been worthily upheld.

At the instance of the Government of the United States a Chamber of Delegates from Foreign Governments to the Congress was constituted, and the Institution was honoured in the appointment of the following from among its members by His Majesty's Government as the official representatives of Great Britain: Colonel R. E. B. Crompton, C.B.; Professor John Perry, F.R.S.; and Dr. R. T. Glazebrook, F.R.S.

The work to which the Chamber of Government Delegates devoted itself was the consideration of Electro-magnetic Units and of International Standardisation. The result of their deliberations has been fully reported on by Mr. Duddell, the Hon. Secretary to the Institution Delegation, and his report has already been published in the Journal.

As a result of a Resolution of the Chamber of Government Delegates at the International Congress at St. Louis, the Institution of Civil Engineers directed the Engineering Standards Committee to consider and report on the proposal to endeavour to secure International Electrical Standardisation. The Main Committee presented their Report in due course to the Institution of Civil Engineers with the request that they confer with the Institution of Electrical Engineers. The President, Mr. Alexander Siemens, has accordingly conferred with the President of the Institution of Civil Engineers, and as the outcome of the Conference a sub-committee of the Engineering Standards

Committee, with the President of the Institution, Mr. A. Siemens, as Chairman, has been formed for the purpose of entering into correspondence with Foreign Countries with a view to ascertain their attitude towards the question of International Standardisation and, if favourable to the idea, to procure their support to the proposal to form an International Commission on Standardisation.

Advisory Committees on Matters affecting the Electrical Engineering Industry.

The Council has been in communication with the Departments of the Board of Trade and Home Office with regard to the revision of the Regulations affecting the use of Electricity, and they were invited during the Recess by the Board of Trade to send in any observations they might wish to offer on the Draft Revised Regulations for securing the safety of the Public and for ensuring a proper and efficient supply of electrical energy. The consideration of the Council was also invited by the Home Office for the Revised Provisions of the Factory Act. The President-Elect, Mr. Alexander Siemens, was Chairman of the Special Committee to which the two questions were referred, and in due course the Committee reported to the Council, and recommendations were made to the Board of Trade and the Home Office embodying the amendments proposed.

On the invitation of the Mining Association of Great Britain the Council in May, 1904, agreed to discuss mutually with that body the Draft Rules of the Home Office relating to Electricity in Mines. The consideration of the drafting of amendments was referred to the Traction Light and Power Committee, with Mr. W. H. Patchell, Vice-President, as Chairman, and much time and care were devoted to the work. Finally, the Committee was empowered to hold a Joint Meeting with the Mining Association in order to exchange views, and the deliberations resulted in the inclusion of many important amendments in the recommendations of the Mining Association to the Home Office.

"Science Abstracts."

Science Abstracts appears to be fully maintaining its sphere of usefulness, and the value of the work is becoming more and more widely recognised; the sales in 1904 to the public were the largest in the history of the publication.

In the course of 1904 the work was brought up to date, involving a considerable expenditure, as the accounts show. An additional 1,199 and 717 abstracts and references for the two sections A and B respectively were published, besides the abstracts from current matter, which numbered 2,140 and 2,248 respectively (2,192 pages in all). Abstracts of papers are now printed as soon after publication as is compatible with proper referencing to the original pages.

In the first quarter of 1905 the proportion of Abstracts published one month after date is, roughly, 40 and 60 per cent. for the two sections respectively, or including papers two months after date, 64 and 82 per cent. Up to and including April, 1,370 abstracts (608 pp.) have as yet been published in 1905.

Wiring Rules.

Some preliminary steps towards issuing a revised edition of the Wiring Rules have been taken, and the Committee who have the matter in hand are awaiting the issue of the Board of Trade and Home Office Revised Regulations before proceeding further with the work of revision.

Petition against the London Buildings Acts Amendment.

The Council have directed their attention to the probable effect of the new Bill to amend the existing London Building Acts, and in view of its many objectionable features it was decided to petition Parliament against the passing of the Bill. A form of petition embodying the grounds on which the Bill, if passed into law, would injuriously affect the interests of the electrical engineering industry was accordingly drawn up in consultation with the Honorary Solicitors and was lodged with the proper authorities at the House of Commons.

Visit to America.

The invitation to visit America and Canada was accepted by a number of members, and during the latter part of August a party of sixty-one members, accompanied by ten ladies, travelled by various routes to America, the majority landing in Boston on September 2nd. Here they were most warmly welcomed by their hosts, who had prepared a comprehensive programme for their entertainment. In each of the following cities an influential local reception committee was formed, and the undermentioned works and places of interest were visited:—

Boston.	Power Station of the Edison Electric Illuminating Company.
	American Telephone and Telegraph Company.
	New England Telephone and Telegraph Company.
	Harvard University.
	Massachusetts Institute of Technology.
New York.	Excursion up the Hudson River (by invitation of J. G. White, Esq.).
	The New Electric Sub-way (Interborough Rapid Transit Company).
	Kingsbridge Power Plant and 96 Street Power House of the New York City Railway Company.
	Manhattan Elevated Power Plant.
	New York Edison Company's Station.
	Laboratory and Workshops of Mr. T. A. Edison.
Schenectady.	Works of the General Electric Company.
Montreal.	Lachine Rapids.
	Station of the Montreal Light, Heat, and Power Company.
	McGill University.
	Forest and Stream Club Dorval.

Montreal.	Shawinigan Falls (Shawinigan Water and Power Company).
	Power House of Lachine Rapids Hydraulic and Land Company.
Niagara Falls.	Niagara Gorge and Falls.
	Niagara Falls Hydraulic Power and Manufacturing Company.
Chicago.	Power Station of the Chicago Edison Company.
	Illinois Tunnel Company's Works.
	Chicago Telephone Company.
	Western Electric Company.
St. Louis.	The International Electrical Congress took place, and a Joint Meeting of the American Institute and the Institution was held at Festival Hall in the grounds of the World's Fair.
Pittsburg.	The Works of the Union Switch and Signal Company.
	The Works of the Westinghouse Electric and Manufacturing Company, of the Westinghouse Machine Company, and of the Westinghouse Air Brake Company.
	Works of the Nernst Lamp Company.
	Works of R. D. Nuttall Company.
	Carnegie Steel Company's Bessemer and Homestead Works.
Washington.	Bureau of Standards.
	United States Capitol.
	Library of Congress.
	Central Power Station.
	Navy Yard.
	Government Printing Office.
	Mount Vernon.
	The Treasury, White House, Washington Monument, etc.
Philadelphia.	Power House of the Philadelphia Rapid Transit Company.
	Main Generating Station of the Philadelphia Electric Company.
	Baldwin Locomotive Works.
	United States Mint.

Two days were spent in New York City, on one of which (September 4th) the visitors were invited as the guests of Messrs. J. G. White and Company to an excursion up the Hudson River, and on September 5th a banquet was given by the American Institute of Electrical Engineers to all the members and delegates, with their ladies, at the Waldorf Astoria Hotel.

While at St. Louis, in addition to the many courtesies and entertainments received at the hands of the Local Reception Committee in that

town, a Reception was held on September 13th by the Associazione Elettrotecnica at the Italian National Pavilion in the World's Fair Grounds, to which all the visiting members of the Institution were invited. This, the leading Italian Society, was represented by its President, Professor M. Ascoli, in company with Mrs. Ascoli, and by a large number of its most distinguished members, who were also visiting St. Louis for the purpose of attending the Congress.

A Reception was held by Colonel Sir C. M. Watson, K.C.M.G., Commissioner-General of Great Britain, and Mrs. Watson, at the British National Pavilion. The special acknowledgments of the Council are due to the Commissioner-General, to Mr. J. H. Cundall, and to the other members of the staff for their kind assistance and courtesy and for many services rendered to the members during their stay in the City.

Before leaving St. Louis the President of the Institution entertained at luncheon at the New York State House in the grounds of the World's Fair as many of the Institution's Hosts and Delegates as were present at the time in St. Louis. The guests, including ladies, numbered upwards of one hundred, and at the close of the proceedings Mr. Gray presented to the American Institute of Electrical Engineers a painting which was a reproduction by Mr. A. Ackland Hunt of his celebrated picture, now at Colchester, representing Dr. Gilbert before Queen Elizabeth.

In acknowledgment of the gift, a handsome Address, printed in old English characters, was presented on behalf of the American Institute to the Council and to Mr. Gray by Mr. T. C. Martin, Past-President of the American Institute of Electrical Engineers, on the occasion of his recent visit to this country. The Address* conveyed in warm terms the thanks of the Sister Institute for the interesting memorial.

The Council desire to express their deep indebtedness to Mr. Bion J. Arnold, the then President of the American Institute of Electrical Engineers, Mr. J. W. Lieb, Junr., the present President, Mr. T. C. Martin, Past-President, Mr. Calvin W. Rice, Vice-President, and Mr. R. W. Pope, Secretary, besides many other firms and individuals, for the very cordial welcome extended to the members throughout their visit, and for the arrangements so excellently planned and carried out for their convenience and entertainment. A tribute is also due to the memory of the late Mr. E. H. Mullin, to whose untiring labours the excellence of the transport arrangements was due. It was with profound regret that the announcement of his death was received, and a cablegram and letter were at once despatched to Mrs. Mullin, in condolence with her in her bereavement.

In acknowledgment of the kind hospitality accorded to the members, an illuminated Address of thanks was prepared and presented to the American Institute of Electrical Engineers, and telegrams and letters of thanks were sent to the Chairmen of the Local Reception Committees, and to the following, who had extended hospitality to the members :—

* A reduced facsimile of the Address faces this page.

To

THE INSTITVTION OF ELECTRICAL ENGINEERS

GREETING:

HAving in mind the many evidences of friendship and good will from the officers and members of your body during their recent visit, as our official guests, to the International Electrical Congress of St. Louis, 1904, and which culminated in the presentation through your distinguished President, Robert Kaye Gray, on September 17, 1904, of the magnificent painting representing Dr. William Gilbert of Colchester before Queen Elizabeth:

The President, Board of Directors and Members of The American Institute of Electrical Engineers, desire to express formally by these presents, their grateful appreciation of the generous and thoughtful gift, and their recognition of the kindly spirit which prompted it.

This masterly representation of an historic scene will always be cherished by us as a testimonial of the warm friendship which, no less than professional ties, binds our Institute with the elder Institution of the mother country. The painting will be displayed in a prominent position in our new headquarters in the United Engineering Building, in honor of the esteemed donor and of its great subject, your illustrious countryman, who gave the world not only the first clear conception of the principles of the magnet, but also the first treatise in which, according to the light of to-day, true scientific method was employed.

We beg of you to accept this official expression of our appreciation of your generosity as a slight token of the high esteem in which your society is held by our Institute.

AMERICAN INSTITUTE OF ELECTRICAL ENGINEERS
FOUNDED NEW YORK 1884

J. W. Lieb Jr.
President.

Ralph W. Pope
Secretary.

The Principal of Harvard University.
The Principal of McGill University, Montreal.
Colonel Sir C. M. Watson, K.C.M.G.
The Right Hon. Viscount Peel, Chairman of the British Commission.
The President of the Montreal Light, Heat, and Power Company.
Mr. C. A. Coffin, President of the General Electric Company.
Mr. J. G. White.
Mr. T. A. Edison.
Mr. G. Westinghouse, President of the Westinghouse Companies, and
Mr. G. W. Davenport, Vice-President and General Manager of the Niagara Falls Power Company.

After the return of the party, a special vote of thanks on behalf of the members was also accorded to the President, Mr. Robert Kaye Gray, by the Council for having so worthily represented the Institution during the visit of its members to America.

Unveiling of the Gilbert Picture at Colchester.

At the invitation of Mr. E. H. Barritt, Mayor of Colchester, the President, accompanied by many members of Council and other contributors to the Gilbert Memorial Picture, visited Colchester on June 11, 1904, for the purpose of witnessing the ceremony of unveiling the picture at the Moot Hall. It will be remembered that this painting by Mr. A. Ackland Hunt was presented to that town in commemoration of the Tercentenary of the birth of Dr. William Gilbert. On arrival a visit was paid by the party to the tomb of Gilbert, and to his birthplace "Tymperley." After inspecting the electric light and power works of the Town Council the party was entertained by the Mayor and Corporation at luncheon. Several other places of interest in the town and neighbourhood were also visited under the guidance of the courteous hosts. The formal ceremony of unveiling was performed in the afternoon by the Mayoress, and at its conclusion she was presented by the President with a gold chain in honour of the occasion. Speeches having reference to the greatness of Gilbert's work as a pioneer in Scientific Research were made by Professor Silvanus P. Thompson, Mr. R. Kaye Gray, Professor John Perry, and others.

National Physical Laboratory.

At the invitation of Sir William Huggins, President of the Royal Society, and of the Board of Management of the National Physical Laboratory, the President and many members visited the Laboratory at Bushy House, Teddington, on March 17. They were received by Lord Rayleigh, the Chairman of the Board, and by Lord Kelvin, G.C.V.O., representing the President of the Royal Society. Dr. R. T. Glazebrook, the Director, and the members of the staff, conducted the visitors over the various departments.

Colliery Exhibition.

During the week of the Colliery Exhibition at the Royal Agricultural Hall, Islington, the Members of Council were entertained at luncheon by the Secretary of the Committee of Organisation, Mr. Greville Montgomery, and they afterwards availed themselves of the opportunity to examine the exhibits showing the application of electric power to mining.

Henry Cort Memorial.

An invitation was received by the Council to appoint a representative to attend the ceremony of unveiling the Memorial erected in Hampstead Parish Church to commemorate the work of Henry Cort. Mr. C. E. Spagnoletti, Past-President, acted as the representative of the Institution on this occasion.

Annual Conversazione.

The Annual Conversazione was held on June 28, 1904, at the Natural History Museum, and was well attended. The new arrangement brought about by the alteration of the Articles of Association having come into force, by which the taking of office by the President-Elect is deferred until the opening of the new Session, the President had the advantage of the support of the President-Elect, Mr. A. Siemens, who was accompanied by Mrs. Siemens and Miss Siemens.

Annual Dinners.

The Annual Dinner was given in the Grand Hall of the Hotel Cecil on December, 1, 1904, the company present numbering 439. The President, Mr. Alexander Siemens, occupied the chair, and a large number of distinguished guests attended. As on the last occasion, an early adjournment was made to the Victoria Hall for conversation.

The Students this year, with the sanction of the Council, inaugurated the holding of an Annual Dinner, which took place at the Holborn Restaurant on March 16, 1905, and was well attended. The Chairman of the London Students' Section, Mr. H. D. Symons, occupied the chair and the guests included the President, Mr. A. Siemens, and a number of Members of Council.

Building Fund.

The Building Fund, which at the commencement of the year 1904 stood at £12,884 0s. 7d., amounted on the 31st of December to £19,398 12s. 4d. The increase, as shown by the Accounts for 1904 now published, is chiefly due to the transfer to the Fund of the sum of £6,000 from the General Fund.

In order to profit as much as possible during the interval which must elapse between the acquisition of the site and the maturing of the plans for erecting a suitable building, the Council has sanctioned the letting on a seven years' lease of such parts of the premises as were adapted for business purposes, reserving to the Institution the right of redemption of the lease on equitable terms at the end of three years

and of five years. The improvements in the neighbourhood have already resulted in a rise in the value of the rents, of which the Institution is now reaping the advantage.

Benevolent Fund.

The Council note with satisfaction that the contributions by members to the Benevolent Fund show an increase over those of the past year. An energetic appeal by the Members of the Committee of Management at Christmas was generously responded to by a large number of members, and it is hoped that these will continue to give donations annually in future on the same scale. The increased receipts have enabled the Committee to invest a further sum of £500, bringing the total amount of the invested Funds to £2,050.

The grants in aid during the year under the rules of the Committee were four in number.

McMillan Memorial Fund.

This Fund, which was opened on the initiative of the Council immediately after the death of the late Mr. W. G. McMillan, amounted by the end of 1904 to £2,082, and the Council has sanctioned the investment of this sum in Trustee Securities for the benefit of Mrs. McMillan and her children. The Trustees appointed to administer the Fund are: Sir W. H. Preece, Mr. Alexander Siemens, and Mr. Robert Kaye Gray.

In view of the impossibility of thanking individually all the kind friends who so generously contributed to the Fund, Mrs. McMillan conveyed her thanks in a letter to the Council, and in accordance with her wish an announcement expressing her gratitude to the subscribers was made at the Ordinary General Meeting on March 23rd.

Wilde Benevolent Fund.

No grant has been made from this Fund during the past year.

Engineering Standards Committee.

The supporting Institutions of the Engineering Standards Committee were recommended early in the current year to concur in a Resolution transferring the Funds of the Committee and the direction of the Committee itself to the legal control of the Institution of Civil Engineers. The Council, in consultation with the Honorary Solicitors, considered very carefully the terms of the Agreement under which the transfer was to be effected, and it was concluded that such an arrangement would in no way prejudice the interests of the Institution of Electrical Engineers as one of the supporting bodies. They therefore concurred with the other supporting Institutions in sanctioning the transfer.

The Engineering Standards Committee during the past year continued their work in connection with the Standardisation of Electrical Machinery, and have issued further valuable Reports on the subject. By the kind permission of the Committee the Reports on Temperature

Experiments carried out at the National Physical Laboratory by Mr. E. H. Rayner were presented for reading before the Institution in March.

Annual Accounts.

The financial position of the Institution continues to be a matter for congratulation by the Council. The excess of Income over Expenditure for 1904 amounts to £2,125 15s. The surplus is not so large as that of the previous year owing to certain exceptional items of expenditure, which are shown in the Accounts. The Annual Statement of Accounts is appended to the Report, and a comparison with the Accounts of the preceding year can readily be made.

Library.

The work of re-organising the Library, which unfortunately received an interruption by the death of Mr. W. G. McMillan, is about to be taken in hand again, and it is hoped that it will be successfully carried through during the next year. The Council have appointed a sub-committee for the purpose of dealing with the matter. Owing to the increasing size of the Journal of Proceedings, it has been found necessary to issue it in future in two volumes annually instead of one, the numbering of the volumes to continue consecutively as they appear.

The accessions to the Library during the period from May 31, 1904, to the date of this Annual General Meeting, numbered 111; nearly all of these have been presented by the authors or publishers.

The supply of Specifications of Electrical Patents and of Abridgments of Specifications relating to Electricity and Magnetism is continued by the kindness of H.M. Commissioners of Patents, and the arrangement is still in force whereby the Specifications of all Electrical Patents published during any week are placed on the Library table on the following Monday morning.

The periodicals or printed Proceedings of other societies received regularly are, with some additions, the same as last year.

The number of visitors to the Library in the twelve months from June 1, 1904 to May 26, 1905, inclusive, has been 442, of whom 28 were non-members.

APPENDIX TO REPORT.

TRANSACTIONS, PROCEEDINGS, &c., RECEIVED BY THE INSTITUTION.

BRITISH.

Asiatic Society of Bengal, Journal and Proceedings.
Cambridge Philosophical Society.
Engineering Association of New South Wales.
Greenwich Magnetical and Meteorological Observations.

Institute of Patent Agents, Transactions.
Institution of Civil Engineers, Proceedings.
Institution of Engineers and Shipbuilders in Scotland.
Institution of Mechanical Engineers, Proceedings.
Iron and Steel Institute, Proceedings.
King's College Calendar.
Liverpool Engineering Society, Proceedings.
Municipal Electrical Association, Proceedings.
National Physical Laboratory Report.
North-East Coast Institution of Engineers and Shipbuilders.
North of England Institute of Mining and Mechanical Engineers, Transactions.
Physical Society, Proceedings.
Royal Dublin Society, Transactions and Proceedings.
Royal Engineers' Institute, Proceedings.
Royal Institution, Proceedings.
Royal Meteorological Society, Proceedings.
Royal Scottish Society of Arts, Transactions.
Royal Society, Proceedings.
Royal United Service Institution, Proceedings.
Society of Arts, Journal.
Society of Chemical Industry, Journal.
Society of Engineers, Proceedings.
Surveyors Institution, Transactions.
University College Calendar.

AMERICAN AND CANADIAN.

American Academy of Science and Arts, Proceedings.
American Institute of Electrical Engineers, Transactions.
American Philosophical Society, Proceedings.
American Society of Mechanical Engineers, Transactions.
Bureau of Standards, Washington Bulletin.
Canadian Society of Civil Engineers, Transactions.
Engineers' Club of Philadelphia, Proceedings.
Franklin Institute, Journal.
Nova Scotia Institute of Science, Proceedings.
Ordnance Department of the United States, Notes.
Western Society of Engineers, Journal.

BELGIAN.

Association des Ingénieurs Électriciens sortis de l'Institut Electro-Technique Montefiore, Bulletin.
Société Belge d'Électriciens, Bulletin.

DANISH.

Tekniske Forening, Tidsskrift.

DUTCH.

Koninklijk Institut van Ingenieurs, Tijdschrift.

FRENCH.

Académie des Sciences, Comptes Rendus Hebdomadaires des Séances.
Société Française de Physique, Bulletin des Séances.
Société des Ingénieurs Civils, Mémoires.
Société Internationale des Électriciens, Bulletin.
Société Scientifique Industrielle de Marseille, Bulletin.

GERMAN.

Verein Deutscher Ingenieure, Zeitschrift.
Verein zur Beförderung des Gewerbfleisses, Verhandlungen.

ITALIAN.

Associazione Elettrotecnica Italiana, Atti.

RUSSIA.

Section Moscovite de la Société Impériale Technique Russe.

LIST OF PERIODICALS RECEIVED BY THE INSTITUTION.

BRITISH.

Cassier's Magazine.
Electrical Engineer.
Electrical Magazine.
Electrical Review.
Electrical Times.
Electrician.
Electricity.
Electro-Chemist and Metallurgist.
Engineer.
Engineering.
Engineering Times.
English Mechanic and World of Science.
Illustrated Official Journal, Patents.
Indian and Eastern Engineer.
Invention.
Iron and Coal Trades Review.
Light Railway and Tramway Journal.
Mechanical Engineer.
Nature.
Page's Magazine.
Philosophical Magazine.

AMERICAN.

American Electrician.
Electrical Review.
Electrical World and Electrical Engineer.
Electricity.
Engineering News.
Journal of the Telegraph.
Physical Review.
Scientific American.
Street Railway Journal.
Street Railway Review.
Technology Quarterly.
Western Electrician.

AUSTRIAN.

Zeitschrift für Elektrotechnik.

DUTCH.

De Ingenieur.

FRENCH.

L'Eclairage Électrique.
L'Electricien.
L'Industrie Électrique.
Journal de Physique.
Journal Télégraphique.
Le Mois Scientifique et Industriel.

GERMAN.

Annalen der Physik und Chemie.
Beiblätter zu den Annalen der Physik und Chemie.
Centralblatt für Accumulatoren und Elementenkunde.
Electrotechnischer Anzeiger.
Electrotechnische Zeitschrift.
Glückauf.
Technische Literatur.
Zeitschrift für Elektrochemie.
Zeitschrift für Instrumentenkunde.

ITALIAN.

L'Elettricità.
Giornale del Genio Civile.
Il Nuovo Cimento.

SPANISH.

La Ingenieria.

The Institution of

STATEMENT OF INCOME AND
ENDING 31st

Dr.

EXPENDITURE.

		£	s.	d.	£	s.	d.
To MANAGEMENT :—							
Salaries		1,338	19	2			
Retiring Allowance		300	0	0			
Accountants' Fees		15	15	0			
Addressing		74	4	0			
Printing and Stationery		427	1	10			
Postage		737	0	11			
Telephone		26	10	0			
Travelling Expenses		11	19	0			
					2,931	9	11
,, PUBLICATIONS :—							
Journal		1,116	0	4			
"Science Abstracts"—							
Disbursements ...	...£2,559 6 4						
Less Receipts ...	... 1,405 12 8						
		1,153	13	8			
					2,269	14	0
,, MEETINGS :—							
Advance Proofs, Refreshments, &c.		153	15	10			
Reporting		71	8	0			
					225	3	10
,, RENT, LIGHTING, AND FIRING					659	11	2
,, INSURANCE					9	15	0
,, DEPRECIATION :—							
Library (5 %)		65	12	6			
Furniture (5 %)		18	11	5			
					84	3	11
,, PREMIUMS					117	13	0
,, CONVERSAZIONE					291	11	4
,, ANNUAL DINNER					73	14	3
,, LOCAL SECTIONS					475	0	6
,, GRANTS :—							
Delegates to St. Louis Congress		600	0	0			
Engineering Standards Committee ...		50	0	0			
					650	0	0
,, ADVERTISING					21	6	1
,, LEGAL EXPENSES					21	0	0
,, MISCELLANEOUS EXPENSES					119	18	5
,, BALANCE carried to General Fund, being excess of Income over Expenditure					2,125	15	11
					£10,075	17	4

EXPENDITURE FOR THE YEAR DECEMBER, 1904.

Cr.

INCOME.

	£	s.	d.	£	s.	d.
By Subscriptions for 1904 :—						
Received	8,672	17	6			
Outstanding (Estimated Value)	540	0	0			
				9,212	17	6
,, Dividends on Investments :—						
Life Compositions	£166	5	9			
General Fund	190	5	3			
				356	11	0
,, Interest on Cash on Deposit				32	9	4
,, Journal :—						
Sales	161	2	10			
Advertisements	284	0	0			
				445	2	10
,, Wiring Rules				14	15	1
,, Model General Conditions for Contracts				14	1	7
				£10,075	17	4

Dr.

	£	s.	d.
To Amount (as per last Account)	5,452	18	0
,, Life Compositions received during 1904	84	0	0
	£5,536	18	0

COMPOSITIONS.

Cr.

				£	s.	d.
By Investments (at cost):—						
£400	0	0	New South Wales 4 % Bonds	414	15	0
318	0	0	Cape of Good Hope 4 % Consolidated Stock	306	0	0
1,679	19	5	India 3½ % Stock	1,776	5	0
120	0	0	South-Eastern Railway 5 % Debenture Stock	204	16	6
355	5	10	Canada 3 % Stock	352	13	6
289	17	4	Midland Railway 2½ % Consolidated Perpetual Preference Stock	274	11	10
6	0	0	East Indian Railway Class "C" Annuity ...	185	1	9
87	0	0	Great Eastern Railway 4 % Consolidated Preference Stock	130	15	2
175	0	0	Great Eastern Railway 4 % Debenture Stock	251	5	5
5	6	4	Great Indian Peninsula Railway "B" Annuity	133	17	6
143	0	0	Southwark and Vauxhall Water Co. 4 % "A." Debenture Stock	207	17	9
520	0	0	Staines Reservoirs 3 % Guaranteed Debenture Stock	539	2	3
200	0	0	Glasgow and South-Western Railway 4 % Preference Stock (1894)	276	5	0
29	0	0	Madras Railway 5 % Stock	44	9	4
60	0	0	South Indian Railway 4½ % Debenture Stock	88	1	4
30	0	0	Burma Railway Co.'s Stock	30	12	3
40	0	0	East Indian Railway 4½ % Debenture Stock ...	57	3	7
				£5,273	13	2
„ Balance uninvested carried to Balance Sheet				263	4	10
				£5,536	18	0

Dr.

				£	s.	d.
To Amount (as per last Account) :—						
Invested...	£10,147	7	9			
Deposit on Purchase Money of Building Site	1,650	0	0			
Uninvested	1,086	12	10			
				12,884	0	7
,, Revenue from Tothill Street Property				364	6	7
,, Subscriptions received during 1904				143	14	6
,, Surplus from Vellum Diplomas				6	10	8
,, Amount transferred from General Fund in 1904				6,000	0	0
				£19,398	12	4

FUND.

Cr.

	£	s.	d.
By Building Site (including Deficit on Realisation of Building Fund Investments)	18,345	10	1
,, Purchase of Lease of 16, Tothill Street	375	0	0
,, Expenses in connection with Purchase of Building Site ...	540	7	0
	£19,260	17	1
,, Balance carried to Balance Sheet	137	15	3
	£19,398	12	4

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount (as per last Account)	2,126	19	3
	£2,126	19	3

SALOMONS SCHOLARSHIP

Dr.

	£	s.	d.
To Amount paid to Scholars in 1904...	75	0	0
„ Balance carried to Balance Sheet	70	5	7
	£145	5	7

DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount (as per last Account)	2,000	0	0
	£2,000	0	0

DAVID HUGHES SCHOLAR-

Dr.

	£	s.	d.
To Amount paid to Scholars in 1904...	50	0	0
„ Balance carried to Balance Sheet	68	7	3
	£118	7	3

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount (as per last Account)	1,500	0	0
	£1,500	0	0

WILDE BENEVOLENT

Dr.

	£	s.	d.
To Amount invested in P.O. Savings Bank	204	8	4
„ „ uninvested carried to Balance Sheet	1	19	6
	£206	7	10

FUND CAPITAL.

	Cr.		
	£	s.	d.
By Investments (at cost) :—			
£1,500 New South Wales 3½ % Stock	1,556	5	9
500 Cape of Good Hope 3½ % Stock	570	13	6
	£2,126	19	3

FUND INCOME.

	Cr.		
	£	s.	d.
By Balance (as per last Account)	75	9	1
„ Dividends received in 1904	69	16	6
	£145	5	7

SHIP FUND CAPITAL.

	Cr.		
	£	s.	d.
By Investment (at cost) :—£2,045 Staines Reservoirs 3 % Guaranteed Debenture Stock	1,998	15	0
„ Balance uninvested carried to Balance Sheet	1	5	0
	£2,000	0	0

SHIP FUND INCOME.

	Cr.		
	£	s.	d.
By Balance (as per last Account)	57	2	2
„ Dividends received in 1904	61	5	1
	£118	7	3

FUND CAPITAL.

	Cr.		
	£	s.	d.
By Investment (at cost):—£875 Great Eastern Railway Metropolitan 5 % Guaranteed Stock	1,493	16	3
„ Amount invested in P.O. Savings Bank	6	3	9
	£1,500	0	0

FUND INCOME.

	Cr.		
	£	s.	d.
By Amount (as per last Account)	158	9	0
„ Dividends received in 1904	43	13	4
„ Interest do. do.	4	5	6
	£206	7	10

BALANCE SHEET,

Dr.

LIABILITIES.

				£	s.	d.
To Overdraft at Bankers' ...				639	0	8
„ Sundry Creditors ...				1,020	12	3
„ Local Sections :—						
Due to Hon. Sec. Birmingham Section ...	2	18	9			
do. do. Glasgow do. ...	8	1	9			
do. do. Newcastle do. ...	3	2	8			
				14	3	2
„ Subscriptions received in advance :—						
On Account of 1905 ...	102	13	6			
do. do. 1906 and 1907 ...	3	4	0			
				105	17	6
„ Salomons Scholarship Fund Income ...				70	5	7
„ David Hughes Scholarship Fund :—						
Capital uninvested ...	1	5	0			
Income ...	68	7	3			
				69	12	3
„ Wilde Benevolent Fund Income ...				1	19	6
„ Entrance Fees ...				2,729	0	6
„ Life Compositions uninvested ...				263	4	10
„ Building Fund ...				137	15	3
„ General Fund :—						
As per last Balance Sheet ...	7,785	2	1			
Add Excess of Income over Expenditure for 1904	2,125	15	11			
	9,910	18	0			
Less Transferred to Building Fund ...	6,000	0	0			
	3,910	18	0			
Less Difference between Estimated Value of Outstanding Subscriptions in last Accounts and Actual Receipts in 1904 ...	8	17	6			
				3,902	0	6
				£8,953	12	0

G C. LLOYD,
Secretary.

We beg to report that we have examined the above Balance Sheet and that we have inspected the Certificates of Investments and the Title Deeds of Balance Sheet is properly drawn up so as to exhibit a true and correct view hereby certify that all our requirements as Auditors have been complied with.

ALLEN, BIGGS & CO.,
Chartered Accountants,
38, PARLIAMENT STREET, S.W.

19*th* *April*, 1905.

Cr.

ASSETS.

			£ s. d.
By Petty Cash			79 11 2
„ Local Sections :—			
Cash in hands of Hon. Sec. Dublin Section ...		3 16 7	
do. do. do. Leeds Section ...		22 7 11	
do. do. do. Manchester Section		13 5 6	
			39 10 0
„ Investments (at cost) :—			
	£1,418 8 0	Midland Railway 2½% Consolidated Perpetual Preference Stock £1,200 0 0	
	918 3 2	India 3½ % Stock 973 17 10	
	52 13 8	Great Indian Peninsula Railway "B" Annuity 1,239 17 9	
	721 0 0	Madras Railway 5% Stock.. ... 1,114 14 0	
	410 0 0	East Indian Railway 4½ % Debenture Stock... ... ... 586 1 7	
	623 0 0	Great Western Railway 5 % Preference Stock 999 18 1	
			6,114 9 3
„ Subscriptions outstanding (Estimated Value)			540 0 0
„ Sundry Debtors			580 7 7
„ Furniture :—			
As per last Balance Sheet		371 8 7	
Less Depreciation (5 %)		18 11 5	
			352 17 2
„ Books, Pictures, &c., other than the Ronalds Library :—			
As per last Balance Sheet		1,277 12 9	
Additions during 1904		34 16 7	
		1,312 9 4	
Less Depreciation (5 %)		65 12 6	
			1,246 16 10
			£8,953 12 0

Statements of Account with the Books and Vouchers of the Institution, and the Tothill Street Property. In our opinion the Statements are correct, and the of the state of the affairs of the Institution as shown by its books. We

F. C. DANVERS
SIDNEY SHARP } *Honorary Auditors.*

On the motion of the President, seconded by Mr. W. H. Patchell, Vice-President, it was resolved, "That the Report of the Council as presented be received and adopted, and that it be printed in the Journal of the Proceedings of the Institution, subject to an alteration, proposed by Mr. S. Sharp, Honorary Auditor, in the paragraph relating to the Building Fund."

The PRESIDENT: The Statement of Accounts has been circulated together with the notice of the meeting; and I will now formally move that the Statement of Accounts and Balance Sheet for the year ending December 31, 1904, as presented be received and adopted.

Mr. R. HAMMOND, Honorary Treasurer: It gives me pleasure to second that resolution, and in doing so, it may not be out of place to dwell upon the Accounts for a few minutes. I may draw the attention of the members to the fact that the result of the year's operations is certainly most satisfactory, for we carry forward a balance of excess of income over expenditure of £2,125. There is also, under the General Fund, a large increase in the amount received in respect of entrance fees. With regard to the £2,125, some who compare these accounts with those of last year may note that we are not carrying forward as much this year as we did last year. That is explicable, because the Council found that, in accordance with the policy which was foreshadowed when they made the last rearrangement of subscriptions, it was well to deal more liberally with the members in certain directions. We accordingly during the last year spent a sum of £871 more than in 1903 on *Science Abstracts* and on the Proceedings. The President has already stated that, with regard to *Science Abstracts*, a large portion of this expenditure is due to our having had to bring up arrears of abstracts when the Institution finally took over the publication. He has also told you that he is sanguine enough to hope that in a short time the *Science Abstracts* income and expenditure will balance. Though I should be very glad indeed if I could share that hope, I hardly feel that this state of things will occur at an early date; in fact, it would appear that in order to give our members more than full value, I was going to say, for their subscriptions, we should be prepared annually to put our hands in our pockets in order to give something in support of *Science Abstracts*. On the other hand, I feel confident that the sum which will have to be paid in future will not be as much as that which was paid during the past year, in view of the fact that the arrears are now made up. We have also been put to a larger expense in the way of rent, and I am sure that all the members will agree that that expense is one which materially benefits the Institution. You will notice that during the past year there has been a slight increase in our contributions to the Local Sections, and I again feel that our members will agree with the policy of the Council that we should strengthen the hands of our Local Sections. Those who are not living in London feel sometimes that the privileges of the Institution are not shared in by them to the extent that London shares them, and during the past year we have

not hesitated, when we considered the applications reasonable, to help the Local Sections. We have also during the past year taken a very bold course by an expenditure in connection with sending a delegation to St. Louis. In fact, in all these directions we have spent rather more freely than we spent in 1903, as may be noticed by the fact that, although our subscriptions were £656 more, our carry forward was £786 less; but the Council trust the members will agree with them that this more liberal expenditure in these important directions has been justified. I have much pleasure in seconding the adoption of the Accounts.

The PRESIDENT: Does any member wish to make any remarks on the Accounts? If not, I will ask them kindly to signify their approval in the usual manner.

The proposal to approve and adopt the accounts was unanimously agreed to.

The President then called upon Sir Henry Mance, Past-President, to propose the resolution placed in his hands.

Sir HENRY MANCE: I have very great pleasure in proposing:—"That the members of the Institution of Electrical Engineers greatly appreciate the privilege of holding their meetings in the rooms of the Institution of Civil Engineers, and hereby tender their hearty thanks to the President, Council, and Members of that Institution for the continuance of their hospitality during the past Session."

And further: "That the members also hereby express their cordial thanks to the Society of Arts, for the great privilege of holding their evening meetings in May in the rooms of that Society."

Mr. W. M. MORDEY, Vice-President, seconded the proposal, and the resolution was carried unanimously.

Mr. H. HUMAN: I have much pleasure in moving that a vote of thanks—I might add a hearty vote of thanks—be accorded to the President and the Council for their services during the past twelve months. It is well known that our President and Council devote a very large amount of their time to the interests of this Institution. It seems to me that we owe it as a sort of duty to ourselves to attend here on an occasion of this kind, because it is the only opportunity we have during the year of expressing our thanks for the services rendered. As long as we have at the head of our affairs such able men as we have had in the past, I feel sure that the future of this Institution is secured. There is one fact I should like to record, and that is, sir, your presence at the Phœnix Fire Office on the occasion of the retirement of Mr. Heaphy. That was not only a very great compliment indeed to me, but it was a kindly act appreciated by all concerned.

Mr. R. J. WALLIS JONES: It gives me very great pleasure to second the vote of thanks proposed by Mr. Human to the President and Council of the Institution. I feel quite sure that all the members appreciate very fully the arduous labours of the Council, and we realise that what they are doing is raising the standard of the Institution immensely. I think the expenditure referred to by the

Honorary Treasurer is thoroughly justified, and that the standing of the Institution is being raised in a very solid and substantial manner. I also feel that it will give great satisfaction to our American friends that Professor Elihu Thomson has been elected an Honorary Member of the Institution. Such acts tend towards good feeling between the two countries. I have much pleasure in seconding the resolution.

The vote of thanks was put, and carried unanimously.

The PRESIDENT then thanked the meeting for their kind expression of appreciation of the work and services of himself and his colleagues on the Council.

Mr. S. SHARP : I have much pleasure in moving that the thanks of the Institution be given to the Local Honorary Secretaries and Treasurers for their services during the past year. I believe the resolution includes the Honorary Secretaries out of the United Kingdom as well as those in the United Kingdom, the Secretaries and Treasurers being one and the same persons abroad. The Secretaries are the means of communication between the Institution here and the members in foreign countries, and in that way it is their duty to keep in touch with the members, and for the Treasurers to bring in the subscriptions which are so needful. The Secretaries of the Local Sections in this country have really arduous work to perform. The amount of time they give and the trouble they take in regard to the protection of the interests of the members in their several localities is worthy of all praise, and it therefore gives me the greatest pleasure to move this resolution.

Mr. H. HUMAN : I have much pleasure in seconding the resolution. I should say that, judging by the admirable papers which have come from the Provinces lately, our local Secretaries have had their hands very full indeed. I not only congratulate them, but second the resolution that has been proposed.

The vote of thanks was carried unanimously.

Mr. H. HIRST, Member of Council : Gentlemen, I think the solicitude with which our Honorary Treasurer supervises the accounts and the amount of valuable time which he devotes to this Institution are matters which are only appreciated by those who have a chance of coming in contact with him. I have very much pleasure in rising to propose—"That the thanks of this Institution be given to Mr. Robert Hammond for his kind services as Honorary Treasurer during the past twelve months."

Mr. R. P. WILSON : I have much pleasure in seconding this vote of thanks to our worthy Honorary Treasurer, Mr. Hammond, which Mr. Hirst has so eloquently proposed. I can only add that the Institution is fortunate in again securing the able services of Mr. Hammond as Honorary Treasurer, for another year, and I am sure the members must highly appreciate the manner in which he has discharged the duties of his office in the past.

The vote of thanks was carried with acclamation.

Mr. ROBERT HAMMOND : Gentlemen, I thank you very much for your kind expression of thanks, and can only say that as long as the

members of the Institution favour me with their confidence I shall be very glad indeed to be responsible for their accounts, and to do my best to keep their finances in order.

Mr. W. H. PATCHELL, Vice-President: I have a double duty now to perform. The first part of the resolution I have to propose is—"That the thanks of this Institution be given to Mr. F. C. Danvers and Mr. Sidney Sharp for their kind services as Honorary Auditors during the past year." Those who have been through the accounts know that the work in connection with them is getting heavier and heavier year by year, but our Auditors still perform it ungrudgingly. The second resolution I have to propose is—"That the best thanks of the Institution be tendered to Messrs. Wilson, Bristows & Carpmael for their kind services as Honorary Solicitors during the past year." The work done by our Solicitors, now that we are becoming landowners and landlords, and in connection with *Science Abstracts* and all the other work that passes through their hands, is very great indeed. I have the greatest pleasure in proposing these votes of thanks to the Auditors and Solicitors.

Mr. J. GAVEY: I have very much pleasure in seconding this vote of thanks. I need add but little to what Mr. Patchell has said, except perhaps that the fact that our accounts are never questioned, and that we never get into any legal trouble, is an eloquent testimony to the value of the services rendered us by these gentlemen.

The resolution was carried unanimously.

The PRESIDENT: I have now to announce that no nominations having been received other than those announced at the Ordinary General Meeting on April 27, the Council nominees are, in accordance with No. 45 of the Articles of Association, duly elected to their respective offices, and the following constitute the Council and Honorary Officers for the twelvemonths, 1905–6:—

President.

JOHN GAVEY, C.B.

The Past Presidents.

The Chairmen of Local Sections.

Vice-Presidents.

Dr. R. T. GLAZEBROOK, F.R.S.
J. E. KINGSBURY.
W. M. MORDEY.
W. H. PATCHELL.

Members of Council.

T. O. CALLENDER.
W. A. CHAMEN.
W. DUDDELL.
S. Z. DE FERRANTI.
FRANK GILL.
F. E. GRIPPER.
J. S. HIGHFIELD.
H. HIRST.
Colonel H. C. L. HOLDEN, R.A., F.R.S.
WALTER JUDD.
GISBERT KAPP.
G. MARCONI.
C. H. MERZ.
C. P. SPARKS.
C. H. WORDINGHAM.

Associate Members of Council.

A. CAMPBELL. | T. MATHER, F.R.S.
A. J. WALTER.

Honorary Treasurer.

R. HAMMOND.

Honorary Auditors.

FREDERICK C DANVERS. | SIDNEY SHARP.

Honorary Solicitors.

Messrs. WILSON, BRISTOWS & CARPMAEL.

Mr. F. C. RAPHAEL then proposed a vote of thanks to the Chairman for the able manner in which he had presided at the meeting, and the vote having been seconded by Mr. F. Pooley, the resolution was put to the meeting by Mr. Gavey, and was carried with acclamation.

The PRESIDENT having expressed his acknowledgment of the vote of thanks, declared that the business of the Annual General Meeting was now concluded.

OBITUARY NOTICES.

JOHN BAILEY died on March 30, 1905, at the age of 74. He entered the service of Messrs. S. W. Silver & Co., of Cornhill, in 1848, and in 1857 he was appointed resident manager of the Works at Silvertown, which were then in an embryo condition. From that date until his transfer to the headquarters at Cannon Street in October, 1900, he remained at Silvertown. Thus he was intimately connected with the rise and growth of the Indiarubber, Gutta Percha, and Telegraph Works, while his unfailing cheeriness and good-nature, which were unaffected by stress of work, together with the intimate knowledge which he possessed of all the details and difficulties which must necessarily arise in connection with a large establishment, made it easy and pleasant to work with him. Mr. Bailey was elected an associate in 1872, and he was transferred to the class of members in 1877. In 1875 he served as an Associate Member of Council.

JOHN THOMAS CONNOLLY died from heart failure following on pneumonia, at the age of 40 years, on July 5, 1905. He served an apprenticeship as mechanical engineer with Messrs. Hayward, Tyler, & Co., in whose service he received a through technical training. He was also an accomplished linguist, and assisted his father, the late Thomas Connolly, in establishing the important electric cable works for Pirelli & Co., Milan, and subsequently carried out extensive works in connection with the manufacture of indiarubber and electrical cable in England, France, Germany, and the United States for Messrs. Shaw & Connolly, the Okonite Co., and others. He was one of the founders of the firm of Connolly Bros., Ltd., of Manchester, and as director of that Company was held in great respect by all with whom he came in contact in business as well as by his workpeople. He was a member of the Northern Society of Electrical Engineers, and was transferred to full membership of the Institution of Electrical Engineers at the time when the former Society was amalgamated with the Institution in 1900.

ALBERT CHARLES FORD, who died in August, 1904, was educated at the Finsbury Technical College. Subsequently he was employed in the ship-fitting department of the Thames Ironworks Company, and in the drawing office of the Brush Electrical Engineering Company. After being for two years Works Superintendent of the Phœnix Dynamo Manufacturing Company, of Bradford, he was appointed engineer of the Notts and Derby Electric Power Company, with whom he was employed at the time of his death. Mr. Ford was elected an Associate of the Institution in 1895, and he was transferred to the class of Associate Members in 1899.

CHARLES A. GAWTHORP, who died on March 15, 1905, in his 36th year, was born in June, 1869. Being of delicate health he was unable to attend ordinary schools in his early years, and was educated privately. In 1889 he matriculated at the Central Technical College, South Kensington, where he remained for three years, leaving in 1892. From 1893 to the time of his death Mr. Gawthorp was in the employ of the North British and Mercantile Insurance Company, for whom he carried out numerous surveys of electrical installations in various parts of the country. Mr. Gawthorp was elected an Associate of the Institution in 1893, and was transferred to the class of Associate Members in 1899.

CHARLES ALEXANDER GERHARDI, who died on April 2, 1905, was born in 1837, and had been connected with telegraphy since 1853, when he entered the Belgian Telegraph Service. In 1856 he entered the Service of the Electric and International Telegraph Company, which he left in 1857 to join the Atlantic Telegraph Company. He was present on board the U.S. steam frigate *Niagara* at the attempts to lay the first Atlantic cable in 1857 and 1858, and also at the final laying of that cable in 1858, when he was attached to the Newfoundland station of the Company till 1859, the cable being then abandoned as unworkable. In 1860 Mr. Gerhardi was appointed by the Submarine Telegraph Company as superintendent of their Channel Islands cable, and later he was put in charge, at London, of the Belgian, Dutch, and German cables. In 1872 he was appointed manager of the Direct Spanish Telegraph Company, which he continued to manage until his retirement in 1902. In 1898 the Queen Regent of Spain conferred on Mr. Gerhardi the Commandership of the Order of Isabel la Catolica. Mr. Gerhardi had been a member of the Institution since 1874.

ARCHIBALD P. HEAD was one of the victims of the railway accident which took place at Mentor, on the New York Central Railway, on June 21, 1905. He was born at Redcar in 1866, and was educated at Clifton College. He was a pupil at the Works of Messrs. Hawthorn, Leslie & Co., of Newcastle, from 1884 to 1888, and on leaving the Newcastle Works he followed the engineering course at University College, London, under Professor A. B. W. Kennedy. On leaving College in 1890, Mr. Head joined his father, the late Mr. Jeremiah Head, in his consulting practice at Middlesbrough, and he founded with him, in 1893, the London firm known as Jeremiah Head & Son. After his father's death he carried on the business alone for a few years until he took into partnership his brother, Mr. B. W. Head. He spent a considerable portion of his time in the United States, where he was managing director and consulting engineer of the Otis Steel Company. It was his practice to visit the Company's Works twice a year, and it was while he was returning home from one of these visits that he met with his death. His firm also represented the interests in Europe of the Wellman, Seaver Morgan Company of Cleveland, Ohio, and he was well known as consulting engineer for the iron and steel

industries both at home and abroad. Mr. Head was elected a member of the Institution in 1898.

HERBERT HENRY EDWARD HEATH died at Cape Town, November 27, 1904, at the age of 31. Mr. Heath was apprenticed to Messrs. H. & J. Dale, London, in 1889, and afterwards joined the Acme Electrical Works of Chalk Farm, N.W. His next post was shift engineer, and afterwards testing officer at the G.P.O. Telegraph Factory, Mount Pleasant, from which position he removed to South Africa in 1896, being employed for two succeeding years on the staff of the Metropolitan District Engineer, Post Office Telegraphs, Cape Town. Subsequently he joined the De Beers Consolidated Mines, Kimberley, as electrical assistant, and remained with them until 1901. This period included the siege of Kimberley, when he took an active part in the work of defence. At the end of 1902, after recovering from a severe attack of fever, he rejoined the Post Office Service in Cape Town with the rank of inspector, which he held until his death. For a considerable time he was honorary secretary to the Cape Town Local Section, displaying therein the same keen interest which had marked his connection with the Institution. Mr. Heath was devoted to his profession, in which he had considerable attainments. His loss was universally regretted, both professionally and personally, by all who were brought in contact with him, and at his death a vote of condolence was passed by the Cape Town Local Section. Mr. Heath was elected an Associate Member of the Institution in 1900.

ROBERT HOLDEN HOUSMAN, who died in May, 1905, was educated at Sydney College, Bath, and at Bromsgrove School. In 1882 he entered Mason College, being one of the first students in engineering; at the end of his course he was made one of the first Associates of the college, a distinction which led to the degree of B.Sc., which was conferred on him in 1901, when the college was merged into the University. On leaving Mason College Mr. Housman was, for some years, with Messrs. Chamberlain & Hookham, where he obtained valuable experience in dynamo and general electrical work, and later he was engaged in similar work in London. In 1895 he was elected to the newly-created post of lecturer on electrical engineering at Mason College, and he established and organised the laboratory in electrical engineering. While at Mason College he devised, in conjunction with Mr. Kapp, the well-known Kapp-Housman test for separating the "no-load" losses which occur in dynamo machinery. Up to the time of his death he took an interest in technical electricity, and was an active member of the Birmingham Local Section. After holding the lectureship for three years, he resigned it when he was appointed scientific adviser to Kynoch's in 1898. Here he was able to take up the study of ballistics, for which he had always had great enthusiasm. He had always taken great interest in the theory as well as the practice of shooting, and had already carried out a series of experiments. At Kynoch's he found the opportunity to continue his

favourite pursuit, and with remarkable ability and experimental skill he devised methods of measuring the pressure of the powder and the velocity of the bullet at every point of its course along the barrel of a rifle. He was a man of wide culture outside his scientific pursuits, and his personal qualities won him the respect and warm regard of his colleagues at the Mason College, and later at Kynoch's. Mr. Housman was elected a Member of the Institution in 1890.

JAMES MELDRUM IRVINE, who died in January, 1905, was one of the engineers in the Post Office Service and was stationed at Inverness at the time of his death. He was elected an Associate in 1883, and was transferred to the class of Associate Members in 1899.

GABRIEL JAMES MORRISON died at his residence on February 11, 1905. He was born in London in 1840, and received his training as an engineer in the firm of Robson, Forman, & McCall, civil engineers, of Glasgow, to whom he was apprenticed, carrying on his studies at the same time at the Glasgow University. Here he came particularly under the genial influence of Professor Sir William Thomson (now Lord Kelvin). His early inclinations led him to devote his attention to electrical science, and he was accustomed to spend the whole of his spare time in the apparatus room at the University, assisting Professor Thomson in his experiments, more especially those connected with the early development of submarine telegraph signalling. He was subsequently appointed an assistant electrician in the Atlantic Telegraph Company, and took part in the laying of the cable in 1858, remaining in Newfoundland in the service of the Company until 1861, after which he returned to Glasgow, and took the responsible position of resident engineer of the Glasgow and Milngavie Railway. In 1863 he left Glasgow and joined the staff of Sir James Brunlees in London as one of his principal assistants, and from this period onwards his activities were mainly confined to the sphere of civil engineering. Eleven years later he commenced practice on his own account in Westminster, but shortly afterwards accepted an offer to proceed to China as engineer-in-charge of the first railway projected in that empire, for which Sir. G. B. Bruce was the consulting engineer. The line was successfully laid and opened in July, 1876, between Shanghai and Woosung, but was soon purchased by the Chinese Government and torn up by them. Mr. Morrison subsequently established himself in business in Shanghai as a civil engineer, and devoted his greatest energies in endeavouring to promote the introduction of a system of trunk lines in China. His efforts in this direction involved the making of numerous journeys through the interior of the country, which gave him unique opportunities for becoming intimately acquainted with the people and their habits. Through his justice and fair dealing he won the especial regard of all native officials with whom he came in contact. Descriptions of his travels appeared from time to time in the proceedings of learned societies, and he was also the author of many papers dealing with the future development of engineering enterprise

in China. He received a silver medal from the Society of Arts for his paper on maps and charts, and also published a book upon "Maps, their uses and construction." Mr. Morrison left Shanghai and returned to London in 1902, where he associated himself with Sir John Wolfe Barry, K.C.B., and Mr. Arthur J. Barry as consulting engineers of the Shangai-Nanking Railway. Mr. Morrison was a Member of the Institution of Civil Engineers, of the Society of Arts of London, and of the Royal Institution. He was elected an Associate of the Institution of Electrical Engineers in 1872, and was admitted to full membership in 1884.

LIONEL H. K. STOTHERD, who died early in 1905, at the age of 39, had been educated at Marlborough College and, from 1884 to 1886, at King's College, London. In 1889 he entered the service of Messrs. Siemens Brothers & Co., with whom he remained until 1898, when he took up an appointment under Sir Benjamin Baker. From 1898 to 1901 on the construction of the Central London Railway and on extensions to the City and South London Railway. In 1902 he became manager of the Electric Railway Signalling Syndicate. Mr. Stotherd was elected an Associate in 1889, and was transferred to the class of Members in 1903.

C. J. SUTHERLAND died on January 20, 1905, in his 34th year. Mr. Sutherland received his training at Faraday House, and from the commencement of his professional life he was associated with central station work. After filling several posts, he was appointed electrical engineer to Hanley Corporation in 1895, and here he was responsible for the large extension of the undertaking during the following three years. In 1898 he was appointed to Worcester, where he designed a large combined lighting and traction station which was completed in 1902. It was after coming to Worcester that signs of ill-health began to manifest themselves, and early in 1900 Mr. Sutherland was granted twelve months' leave of absence. He resumed his duties in 1901, but a recurrence of his illness necessitated his resignation shortly before his death. Mr. Sutherland was elected a Member of the Institution in 1902.

GEORGE HAROLD SWETENHAM, who died on the 30th of June, 1905, at the age of 33, was partly trained at the Finsbury Technical College. He was in the employ of the P. & O. Company as electrical engineer on ss. *Shannon* and ss. *Arcadia*, from 1894 to 1896, and subsequently he was appointed assistant engineer-in-charge at the Davies Street Station of the Westminster Electric Supply Corporation. Mr. Swetenham was elected an Associate Member in 1904.

ERNEST TALBOT was born at Smethwick on the 30th of September, 1857, and educated at King Edward's Grammar School, Birmingham. He obtained his engineering training at the lighthouse works of Messrs. Chance Brothers & Co., under the late Dr. John Hopkinson,

and in 1880, when the latter commenced private practice in Westminster, Mr. Talbot became his principal assistant, being employed in connection with various works, chiefly installations of electric lighting and electric traction, upon which Dr. Hopkinson was engaged. On the death of his chief in 1898, Mr. Talbot entered into partnership with Messrs. Charles and Bertram Hopkinson, to carry on the consulting practice established by Dr. Hopkinson, and between 1898 and 1903, when the partnership was dissolved by mutual consent, he was consulted by many local authorities and others in connection with electric-lighting and electric-traction schemes. In conjunction with Dr. Hopkinson, he carried out the initial installation of electric tramways in Liverpool, and later he completed the conversion of the Leeds tramways to electric traction. Mr. Talbot died on the 5th of May, 1904, in his 46th year. He was elected an Associate of the Institution in 1891, and was transferred to the class of Members in 1899.

JOHN VERITY, who died on April 6, 1905, at the age of 41, was educated at University College School. After spending four years on the continent of Europe, he went to America, where he had experience of the production of the earliest incandescent electric lamps. Returning to England, he joined the firm of B. Verity & Sons, and soon after the Crystal Palace Exhibition of 1882 he turned his attention to the manufacture of electrical material on a large scale. The works, which were at first at Covent Garden, were transferred to Aston, near Birmingham, in 1891, and were considerably enlarged in 1896 and in 1904. Mr. Verity, who was a Justice of the Peace for the County of Warwick and High Sheriff of the County of London, was elected an Associate of this Institution in 1888, and was transferred to the class of Members in 1889.

MAJOR-GENERAL CHARLES EDMUND WEBBER, C.B., Past President and Honorary Member of the Institution, died on September 23, 1904, at Margate, at the age of 66 years. There was thus terminated, to the deep regret of many friends professional and social, a career which was characteristic for its activity and its great and varied services to electrical science, and particularly to the development of telegraphy. General Webber was the son of the Rev. T. Webber, of Leekfield, County Sligo, and he entered the Military Academy of Woolwich in 1853, passing out in the Spring of 1855 as a Lieutenant in the Corps of Royal Engineers. He served in this branch with more than usual distinction for thirty years, and was fortunate in having many opportunities on active service of developing interesting problems, building up a practical experience which enabled him, after leaving the army, to attain in the commercial world a large degree of success.

After taking his Commission he was sent to Chatham, where he received instruction for several months in connection with military works. He proceeded at the end of 1857 to India, where he served with the colours for two years, doing signal service, during the Mutiny,

at the sieges of Chandaree and Jhansi, and in the battles of Betwa, Koonch, Calpee, and Gwalior, and in many minor engagements.

On his return home he was engaged on the designs and plans of Newhaven fortifications. Then from November, 1861 until May, 1866 he was Instructor in Surveying and Topography at the Royal Military Academy at Woolwich, and afterwards was attached to the Headquarter Staff of the British Army in the Austro-Prussian War, 1866, for the purpose of reporting on the engineering operations, including the Military and National Telegraphs. In 1867 he attained the rank of Captain.

The most important civil service which he rendered to the nation was during the time he was employed on Postal Telegraph Service from 1870 to 1879, when he was placed by the Postmaster General in command of the Royal Engineers employed by the Department as Divisional Engineers, first in the Eastern and subsequently in the Southern Division of England. It was here that his special training in the field, and particularly his great resource in connection with difficulties, proved of invaluable service. He possessed a faculty of imparting information which made him an exceptionally excellent educator. While an officer under the Postmaster General he trained over three hundred non-commissioned officers and soldiers in the work of telegraphy.

When the first Boer War broke out in South Africa in 1879, General Webber accompanied Sir Garnet Wolseley in the capacity of Adjutant-Quartermaster-General, and during the two years there he did signal service in connection with the operations. Soon after his return he proceeded with Wolseley on the Egyptian Expedition in 1882 as Staff Officer for Telegraphs, with the rank of Quartermaster-General, and he was present at the battle of Tel-el-Kebir. On the subsequent Nile Expedition of 1884–1885 he was Director of Army Telegraphs, and on completion of these operations he retired from the service in 1885 with the honorary rank of Major-General. He was mentioned six times in despatches, and earned three medals with clasps. The order of C.B. was conferred upon him in connection with his work in Egypt, and he earned the further distinction of the decoration of Medjidieh.

Upon his retirement he became the first Managing Director of the Anglo-American Brush Electric Light Corporation, and in this capacity was intimately associated with the early application of electric lighting, not only in London but in other centres. General Webber continued his association with electric lighting in the Metropolis up till 1892 as Consulting Engineer of the City of London Pioneer Company and of the Chelsea Electric Supply Co., as well as of other companies throughout the country. He also rendered valuable services in connection with many of the Exhibitions which twenty and twenty-five years ago had an important influence upon scientific and commercial developments.

His important services to the Institution, which, in fact, owes its inauguration largely to his efforts, are of course well known to all members. In co-operation with Colonel Sir Francis Bolton he founded the Society

of Telegraph Engineers in 1871, which in 1889 became the Institution of Electrical Engineers. With the exception of a few short intervals he was a Member of Council from the time of its foundation, and for a number of years he held the offices of Honorary Treasurer and Trustee. In 1882 he was elected President, and in 1904, in recognition of his distinguished services to Electrical Science, the Council elected him an Honorary Member. He contributed nine papers to the Institution dealing with the Military Telegraphs in Egypt, in the Nile Expedition and in Field Manœuvres, with the application of electricity in the City and Metropolis, and with the electro-chemical treatment of ores containing precious metals; all his papers being essentially practical and informing. Up to the time of his death he continued to take an active part in the management of the Institution, manifesting a keen interest in its welfare, and missing no opportunity of extending its usefulness and prestige. He was a most active member of the Library and Editing Committee, and took a keen interest in the encouragement given to writers of papers, and to Students.

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[P] signifies a reference to the general title or subject of a Paper.

[*p*] signifies a reference to a subject incidentally introduced into a Paper.

[D] signifies a reference to remarks made in a Discussion upon a Paper, of which the general title or subject is quoted.

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[*Ref.*] signifies a reference to the place of publication in the Technical Press of a Paper read at a Local Section, and not yet printed in this Journal.

Note.—The lists of speakers in the Discussion upon any Paper will be found in the Table of Contents at the beginning of the volume.

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